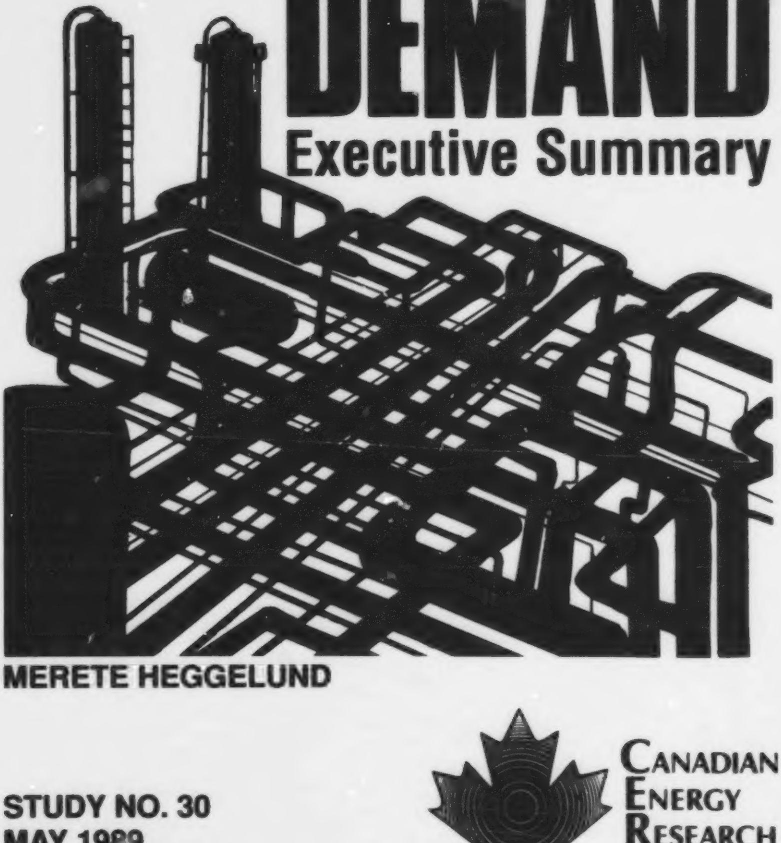
INDUSTRIAL NATURAL GAS DEMAND

Executive Summary



MERETE HEGGELUND

STUDY NO. 30
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CANADIAN
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RESEARCH
INSTITUTE

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Preface

Initiated in January 1988, the research for this study was completed in April 1989. The complete report is also available from the Institute.

The author wishes to thank the five-member Advisory Committee for the direction and constructive criticism provided. Thanks are also extended to the many experts from governments and industries who generously contributed their time and insight. In particular, access to the ISTUM model, granted by Dr. Mark Jaccard with the Natural Resource Management Program at Simon Fraser University, greatly aided the research. Reports provided by the GERAD group at University of Montreal outlining results from the MARKAL model were also of great assistance. ROBBERT Associates ran the SERF model, generating the final study results.

Special thanks are due to a number of the Institute's staff. Garry Sawka contributed valuable research assistance during the summer and fall of 1988, while Susan Wilson assisted in the initial stages of research. Janice Morrison, Beverly Kovacs and Michele Irvin typed numerous drafts. Megan Murphy created the graphics and Vance Lickiss provided computer support. Zaytoon Janjua and Wendy Faid of the I. N. McKinnon Memorial Library gathered source materials from across the continent. Dr. Gerry Angevine, Anthony Reinsch and Morgan MacRae provided their support and guidance throughout the project.

EXECUTIVE SUMMARY

The industrial sector represents the largest end-use market for natural gas in Canada. These consumers provide large and stable baseload demand for natural gas producers and distributors. To continue to serve this market competitively in the future, it is important to understand and anticipate the future energy needs of this sector.

The objectives of this study were to examine the energy use patterns of major industrial consumers to assess:

- how future production technologies are likely to impact on energy demand in the long run; and
- the magnitude of these effects on natural gas demand.

The bulk of the study consists of a detailed exposition of industrial processes, describing where and how energy is used in each of the energy-intensive industries.

Detailed process analyses are provided in Chapters 2 through 5 for the following industries:

- pulp and paper
- iron and steel
- petroleum refining
- chemicals
    - petrochemicals
    - inorganic chemicals
    - fertilizers

These industries account for less than 20 percent of Canada's manufacturing shipments. However, they represent in excess of 54 percent of both total energy demand and total natural gas demand from the manufacturing sector. In addition, specific scenarios for cement production and aluminum smelting are developed in the study.

Recognizing that energy is only one factor of production, industrial energy demand ultimately depends on demand for the final manufacturing products. For the primary industries, this demand comes largely from other secondary manufacturing industries. For example, chemical products are needed to manufacture pulp and paper. To generate the total production paths for each industry, all such inter-industry links must be taken into account.

The Socio-Economic Resource Framework (SERF) at the University of Waterloo was accessed to provide the required overall framework for the analysis. SERF is a demand-driven, input-output based model. Domestic final demand is calculated based on demographic variables such as household structure and population growth. This demand feeds through the industrial input-output system to take into account all the feedback effects between industries. Total manufacturing production is then determined as the sum of total domestic demand and export volumes.

Given this overall framework, the analysis concentrated on generating energy intensity parameters for each industry, to enter into SERF's input-output structure. These parameters reflect a likely scenario of the impact of new production technologies in each industry. In other words, changes in purchased energy per constant dollar output was forecasted for each energy form in each industry to reflect the net effects of energy conservation and efficiency changes, and penetration of new production processes. SERF was then used to generate internally consistent production paths for each industry which, when multiplied with the energy intensity parameters, provided the total industrial energy demand outlook for each fuel.

The Pulp and Paper Industry

Quebec, Ontario and B.C. are the main pulp and paper producing regions in Canada. While pulp and paper are often produced in separate plants, a fully integrated pulp and paper mill would include all of the following steps:

- raw material harvest, collection and transport;
- wood preparation: debarking (and chipping);
- pulping (chemical or mechanical);
- bleaching (if required);
- pulp stock preparation: cleaning, screening and mixing;
- sheet formation;
- pressing;

- drying; and
- finishing: coating, cutting and binding.

The pulp and paper industry has been quite successful in implementing energy efficiency measures such as housekeeping and process control, increased use of waste fuels and waste heat recovery systems. The past trend of more than 2 percent average annual improvements in energy efficiencies cannot be expected to continue unabated. Many of the one-time improvements in efficiency have been implemented, but conservation opportunities remain, for example in high efficiency boilers and burners, waste heat (especially steam) recovery and upgrading, increased use of hog fuels and cogeneration displacing purchased and other self-generated electricity.

The other commonly discussed trend is the increased electricity intensity of production processes. There are process changes underway that favour increased electricity use. Increasing emphasis on the environment may speed the implementation of some advanced chemical recovery technologies. Plasma gasification, mechanical vapour recompression and membrane separation processes all require increased electricity consumption. In addition, medium and high consistency pulping technologies increase electricity use, due to increased pumping needs through bleaching, washing, screening and storage systems. Developments towards more thermo-mechanical and chemi-thermo mechanical pulping capacity and a higher proportion of secondary, higher value added products will also lead to greater electricity intensity of production. In the dryer section, natural gas and electrical infrared drying technologies will compete, potentially replacing steam drum drying, especially in high quality, specialty paper production. For the heavier product grades, impulse drying will likely begin to penetrate.

Between increasing use of waste fuels, conservation and recovery of process heat, and new electrical processes, natural gas consumption appears to be under strong pressure in the pulp and paper industry. The crucial question becomes to what extent higher electricity end-use demand will be satisfied through increased implementation of natural gas-based cogeneration facilities.

In the base case, total energy demand from the pulp and paper industry grows from 312 PJ in 1982 to 401 PJ in 2015, close to 1 percent per year. Natural gas demand grows from 91 PJ to 105 PJ over the period, while fuel oil demand grows from 120 to 127 PJ.

Electricity demand growth outpaces the thermal fuels by far, in accordance with the assumption of increased electricity intensity of production. Growing at an annual average rate exceeding 2 percent, electricity use increases from 92 PJ to 158 PJ over the period. These results are shown in Figure 1.

The consequence is clearly seen in the distribution of market shares, shown in Figure 2. While the relative share of all the thermal fuels including natural gas decline, electricity's market share increases by more than 10 percentage points.

The increased electricity dependency of this industry represents a challenge to natural gas suppliers. Pulp and paper production is the single largest energy-consuming manufacturing industry today, and as these results indicate, substantial changes in energy use patterns may take place over the next 30 years. The export dependency of this industry will place additional pressure on pulp and paper producers to invest in new technologies in a continuous effort to improve efficiency and productivity.

The Iron and Steel Industry

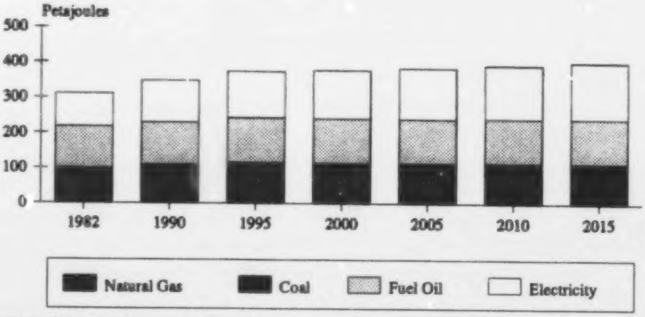
In a fully integrated iron and steel mill, the production process can be broken down into the following steps:

- preparation of raw materials: coke, ore and limestone;
- pig iron production;
- crude steel production;
- rolling of semi-finished products (blooms, billets and slabs); and
- rolling and finishing final products.

Unlike most other primary manufacturing sectors, the steel industry bases substantial production on recycled scrap. Prepared scrap is introduced at the crude steel production stage, varying from 25 to 35 percent of the charge in a basic oxygen furnace to a maximum of 100 percent in an electric arc furnace. Steel making from scrap may therefore preclude the first two stages of the process. Many plants are exclusively involved in the last stage of production, converting semi-finished to final products.

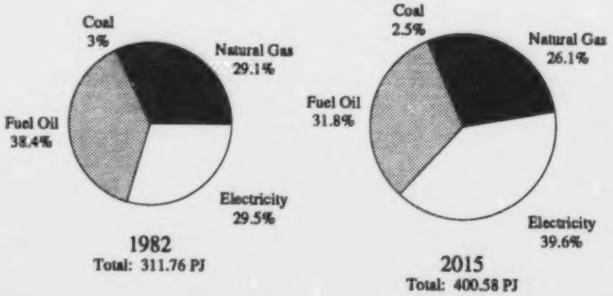
Energy intensity of steel production is around 23 GJ/tonne raw steel. Efficiency improvements in this industry have been lower

Figure 1
Pulp and Paper Industry Energy Demand
Base Case



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

Figure 2
Pulp and Paper Industry
Energy Fuel Shares



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

and somewhat erratic in response to low capacity utilization, rationalization efforts and variable scrap availability and ore qualities.

Process and material changes, such as increased furnace capacities, higher temperatures, injection of hydrocarbons other than coke and higher quality raw materials, have over time reduced the coking rate. This is the amount of coke required for pig iron production. It is essential for an energy-efficient integrated steel operation that full use is made of the waste gases produced. The heating value of coke oven and blast furnace gas can exceed that of purchased natural gas.

The electric arc furnace represented a fundamental change in steel making operations. Electric melting of scrap can reduce the energy intensity of production by almost two-thirds, as the most energy intensive component, the blast furnace plant, is eliminated. Electricity consumption per tonne increases by a factor of approximately 2.7 with electric steel making. The largest natural gas applications of reheat, heat treating and finishing are retained, and without the waste gases available, natural gas expands its potential in these areas. As a consequence, natural gas intensity of production in an electric steel making operation tends to be slightly higher than in an integrated plant. New developments include highly efficient, hybrid natural gas-electricity technologies for scrap melting, expanding the potential natural gas end-use market in electric steel making.

The challenge to natural gas in this industry is the increasing competition from electricity in the reheat and heat-treating markets. Continuous casting, hot charging, direct rolling and thin steel casting represent developments that increase the automation and integration of steel making operations. These integrated processes change the reheat requirements to maintaining, supplementing and equalizing heat, rather than heating a work piece from ambient temperatures.

Substantial electricity savings are also possible in this industry. High-power electrical furnaces, high-efficiency motors and general load management demonstrate substantial electricity conservation potentials. Advanced electro-technologies such as plasma and vacuum furnaces are only expected to penetrate as capacity additions (rather than replacements) in production of high-value, speciality products.

The deployment of third-generation steel making technologies, developing from blast furnace through direct reduction and now to direct smelting, depends crucially on the price and availability of scrap. If such processes become competitive with traditional blast-furnace operations, the flexibility of smaller electric-arc mills could be enhanced. In addition, as thin steel casting is developed, electric mills may be better able to move into production of the whole range of products, again increasing the competitive pressures on traditional large-capacity, integrated mills.

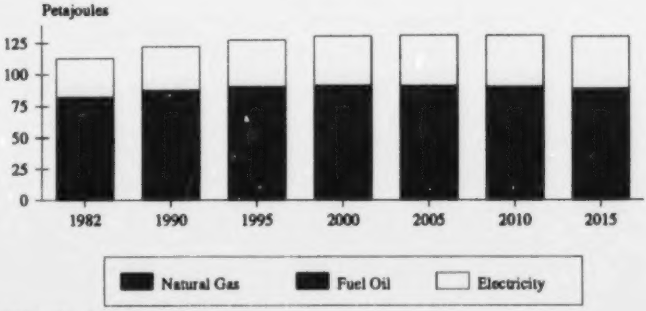
Cogeneration has not demonstrated the same potential in iron and steel operations as in the pulp and paper industry. However, other self-generation options ought to be examined and pursued, considering the potential threats to traditional end-use markets and the potential penetration of electrical steel making. Natural gas generators can be built to withstand the electric transients associated with firing electric-arc furnaces.

The total growth in energy demand averages less than 0.5 percent per year over the entire period, as Figure 3 illustrates. In fact, demand grows from 113 PJ in 1982 to a peak of 132 PJ in 2007, but declines slightly through the last decade to just below 131 PJ by 2015. Natural gas grows from 62 PJ to a peak of 69 PJ in 1998 and subsequently declines, approaching the initial demand level again by 2015. Both electricity and fuel oil demand grow very slowly throughout that period. Coal use is insignificant since metallurgical coal is considered a feedstock and therefore not accounted for in this analysis.

As Figure 4 shows, the relative changes in market shares are notable. Natural gas is expected to lose ground relative to other fuels in this market and, as well, the size of the total market is expected to start declining in the last decade of the forecast period.

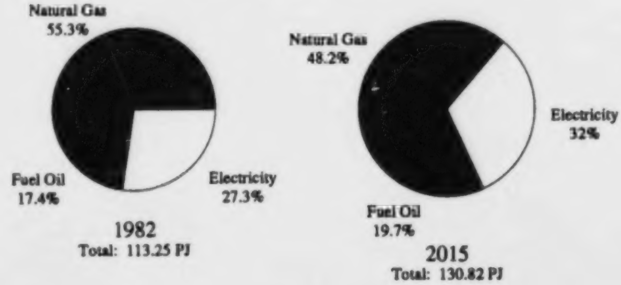
Keeping on top of rapid technological developments represents the major challenge for both consumers and producers of energy in this industry. The results indicate that natural gas is under competitive pressures from other energy forms, in particular electricity, and that fundamental production changes can potentially reduce total energy consumption, and thereby also total natural gas demand.

Figure 3
Iron and Steel Industry Energy Demand
Base Case



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

Figure 4
Iron and Steel Industry
Energy Fuel Shares



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

The Petroleum Refining Industry

Using a full-scale, complex refinery as a reference, the production steps fall into three categories: separation, conversion and upgrading.

Separation involves the initial topping process of:

- atmospheric distillation; and
- vacuum distillation.

Conversion processes convert heavy fractions to light, increasing the yield of valuable light-end products. These processes include:

- thermal cracking;
- catalytic cracking;
- hydrocracking;
- catalytic reforming;
- alkylation; and
- isomerization.

The degree of complexity of these units differentiates between a complex and an integrated refinery. While cat cracking is the most important of these processes, hydrocracking has emerged as an important way of adding versatility to a refinery.

Finally, the most important of the upgrading processes is:

- hydrotreating.

Upgrading serves to stabilize the product and remove undesirable elements.

The petroleum refining industry can be classified as a very large energy user, with the qualification that a large proportion (approximately 70 percent) of total energy requirements are self-produced. The most important purchased energy forms are electricity and natural gas, since refinery gas and petroleum coke are self-generated.

Energy is required to raise the temperature of the oil being processed. The types of equipment for these direct heat applications fall into two categories: direct-fired heaters and furnaces. Thermal processes such as coking and visbreaking require furnaces to crack the hydrocarbon molecules. These furnaces rely on gaseous fuels. Most direct-fired heaters have dual-fuel capability, switching between fluid and gaseous fuels, but in the processes requiring high feedstock temperatures such as vacuum distillation, hydrocracking, catalytic reforming and hydrotreating, gaseous fuels are preferred. Electricity is used in pump and fan motors. The potential for cogeneration is perceived as very limited, but electricity is frequently self-generated in a refinery.

Variations in a refinery's internal consumption of refined petroleum products will occur as a result of market induced process swings, changing the availability and value of distillate and residual oils, refinery gas, petroleum coke and tar. Natural gas is essentially consumed as a supplement to refinery gas to ensure a constant availability of gaseous fuels.

The reported energy efficiency gains have been substantial for this industry. The Canadian Industry Program for Energy Conservation (CIPEC) reported a 30 percent efficiency gain by 1987 over the 1972 base year. However, substantial adjustments have been made to obtain this figure, correcting for increased energy use due to higher process severity and stricter sulphur emissions. The actual fuel use intensity has only declined by about half of this amount.

Energy efficiency measures will continue to be implemented, while a heavier crude feedstock coupled with increased demand for light-end products will work against declining energy intensities in the refining process. Efficiency improvements range from housekeeping and reduced stack and radiation losses, to penetration of high efficiency burners and furnaces. Advanced computer control systems continue to improve the inter- and intra-process flows.

The direction of technological change in the refining industry will be product driven. The demand for high octane products at the retail level, the accelerated schedule for the phasedown of lead additives in 1990 and increased product desulphurization requirements, have all increased refiners' efforts to obtain new technologies that improve process and product mix flexibility. Major avenues of change in this regard include improved catalysts and advanced computer control and process optimization techniques. Increased demand for light-end, high-octane products will initially put pressure on refiners' cat cracking facilities, and eventually lead to increased investment in hydrocracking and isomerization capacity for conversion, and increased upgrading by hydrotreating. The development towards more complex and integrated refineries also enhances the availability of refinery gas. This strengthens the conservation potential for purchased thermal fuels.

Conservation opportunities exist for electricity as well. However, more complex refineries require increased motor and pumping drives, and increased hydrogen production, as investment in hydrocrackers takes place to fulfill octane requirements. Greater oxygen production will also be required for regeneration of catalysts. Such trends will tend to cancel out electricity efficiency gains.

As the results in Figure 5 indicate, total energy demand is predicted to stagnate around 54 PJ in the reference case, after temporarily dipping towards 50 PJ before the turn of the century. Natural gas demand, initially exceeding 43 PJ, bottoms out below 39 PJ and recovers to slightly less than 41 PJ in 2015. Electricity demand experiences a smaller initial decline and exhibits a slight net increase from 12.4 PJ to 13.3 PJ over the period. The initial decline in energy demand is a result of capacity rationalization in the 1980s.

Electricity and natural gas represent very close to 100 percent of purchased energy for this industry. The small shift in relative market shares in favour of electricity is barely perceptible from Figure 6.

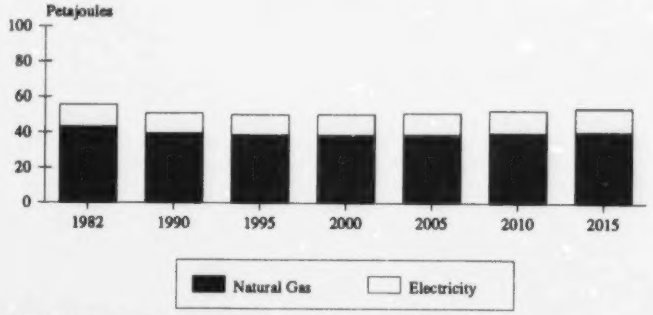
The magnitude of the changes foreseen for this industry are small, as the major proportion of production is not exported and no dramatic technological changes are foreseen. Providing consumer expenditure patterns are not significantly altered, petroleum refineries can be expected to continue to represent large and stable natural gas consumers.

The Chemical Industry

The study considers the petrochemical, inorganic chemical and fertilizer industries separately. For this summary exposition, only industrial chemicals sector results are presented. This sector is dominated by the petrochemical industry, but includes inorganic chemical production as well.

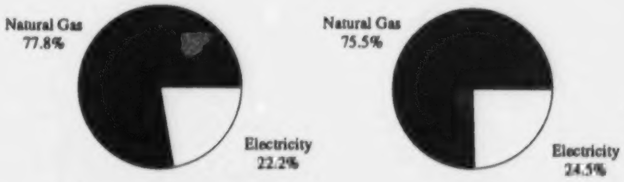
The petrochemical industry uses hydrocarbons primarily as raw materials but also as a source of energy. The two petrochemical processes most dependent on natural gas feedstocks are the production of methanol and ethylene. Aromatics production, on the other hand, is to a larger extent based on crude oil products, although aromatics are also by-products of the ethylene process. Because of the chemical

Figure 5
Petroleum Refineries Energy Demand
Base Case



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

Figure 6
Petroleum Refineries
Energy Fuel Shares



1982
Total: 55.6 PJ

2015
Total: 54.2 PJ

SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

versatility of ethylene, it is commonly considered the most important building block of the petrochemical industry.

Production of ethylene involves steam cracking (or pyrolysis) of the hydrocarbon feedstock at high temperatures and low pressures. The cracked gas products are then charged to quench-towers where the aromatics-rich pyrolysis gasoline and other heavy products are separated. Ethylene and propylene are fractioned off by compression and condensation at gradually lower temperatures.

After initial desulphurization of the natural gas feed, production of methanol takes place by steam reforming natural gas to synthesis gas. Cooled and compressed synthesis gas is fed to a catalytic converter producing crude methanol. Heavy and light-end fractions are separated in distillation units, to produce the pure methanol residual.

The pyrolysis heaters used in ethylene production, as well as the reforming furnaces used to produce methanol and ammonia, are very similar to the direct-fired heaters and furnaces used in the petroleum refining industry. These heaters and furnaces rely on firing gaseous fuels. Since the off-gases available in refineries are not found to the same extent in petrochemical plants, direct heat requirements are largely satisfied by purchased natural gas. An exception is methane as a by-product of ethane pyrolysis, which can fulfill the direct-heat requirements of an entire ethylene plant. Hydrogen is another valuable by-product that can either be used internally or sold.

In the petrochemical and ammonia processes, large amounts of steam are also produced from the quenching operations. This steam can be recovered for both process heat and electricity generation purposes.

The industrial chemical industries have exhibited an impressive overall improvement in energy efficiency. The industry reached close to 40 percent lower energy intensity of production in 1987 compared to 1972, according to CIPEC. Natural gas and electricity dominate as purchased energy forms.

Two significant trends appear from examining the effects of these energy efficiency improvements. First, natural gas has increased its relative market share by more than 10 percentage points over the period. This increase came largely at the expense of residual fuel oil.

Off-oil incentive programs, coupled with deregulation and lower natural gas prices aided this substitution process. This trend has now subsided. Secondly, there has been a slight decrease in the market share of purchased electricity. The trend is due to conservation efforts and increased use of cogeneration.

The industrial chemical industry has been identified as a sector with substantial remaining potential for cogeneration. New electrical technologies are not expected to be implemented on a large scale over the forecast period. While advanced membrane technologies may have a potential in high value-added, derivative products, they are not predicted to penetrate significantly in production of the primary products. Continued improvements in housekeeping, process control, process balancing, automation, and heat recovery and upgrading will contribute to energy efficiency gains. The average intensity decline for total energy consumption in chemicals manufacturing is forecasted at 0.5 percent per year.

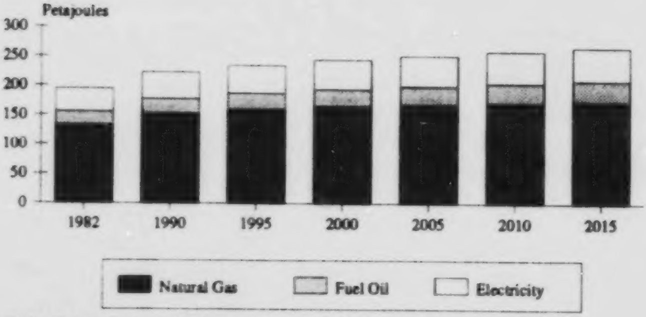
Even when feedstocks are not included, the industrial chemicals industry is the largest natural gas consuming manufacturing industry. Natural gas captured a market share of almost 69 percent of purchased energy in 1982. The reference case demand for energy is illustrated in Figure 7. Total demand increases significantly from 196 PJ to 267 PJ over the forecast period. Natural gas use grows from 134 PJ to 174 PJ, electricity from 39 PJ to 56 PJ and fuel oil from 22 PJ to almost 35 PJ by 2015.

The relative market shares are not significantly affected, although the natural gas share declines by 3 percentage points benefiting the fuel oil and electricity shares. The evolution of these shares is shown in Figure 8.

The Cement Industry

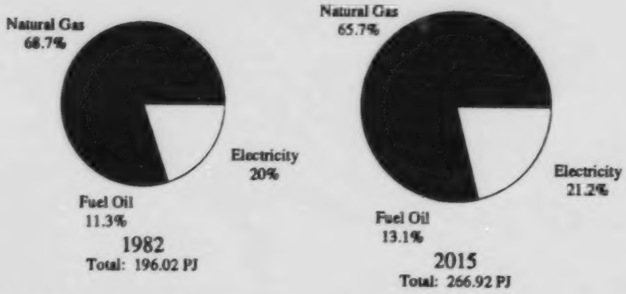
Cement production represents a highly flexible manufacturing process in terms of energy use. Producers can generally switch quickly between a variety of fuels, providing investments in expensive fuel handling systems are not required. Thermal energy is used as kiln fuel, and these kilns have undergone important technological developments in the past, evolving from the long wet process to the dry process which now represents 83 percent of Canadian cement capacity. This change has been a source of substantial energy savings, as heat is only required for the chemical reactions involved in calcination and

Figure 7
Industrial Chemicals Energy Demand
Base Case



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Figure 8
Industrial Chemicals
Energy Fuel Shares



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

clinkering, not for evaporating the water content of the slurry, as in the wet process.

Future developments include the additions of preheaters and precalciners and the wide-spread adoption of more efficient kiln structures such as rotary kilns. Efficiency gains from these changes will gradually penetrate over the next 10 to 20 years. Fluidized bed reactors are perceived to have limited economic potential in the forecast period.

The flexibility in choice of fuel sources means that conventional thermal fuels such as natural gas must compete with coal, pitch, wood pellets and even municipal waste, subject to environmental approval for burning such alternatives. Mechanical energy is used mainly for grinding clinker to cement.

Total energy demand in cement production grows at approximately 1.7 percent per year, from 38 PJ to 59 PJ over the forecast period. Natural gas constitutes the largest single energy source, growing from almost 17 PJ to 24 PJ by 2015, as Figure 9 indicates. Demand for the second largest energy form, coal, also exhibits substantial growth over the period, from 11 PJ to well over 18 PJ in 2015.

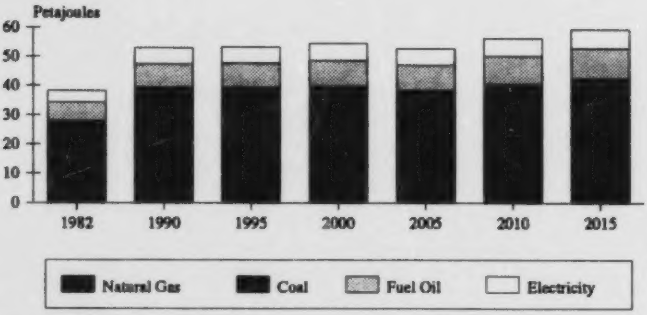
In terms of market shares, the natural gas share decreases slightly, mostly to the benefit of coal, which increases its relative share by 2 percentage points. The evolution of these shares is shown in Figure 10.

These results indicate that the cement industry will remain a very important energy user, with growing demand for total energy in the future. The flexibility of the cement production process with respect to fuel choice and the potential savings involved from investment in energy-efficient technologies, underlines the importance of understanding and anticipating the needs of this energy consuming industry.

The Aluminum Smelting Industry

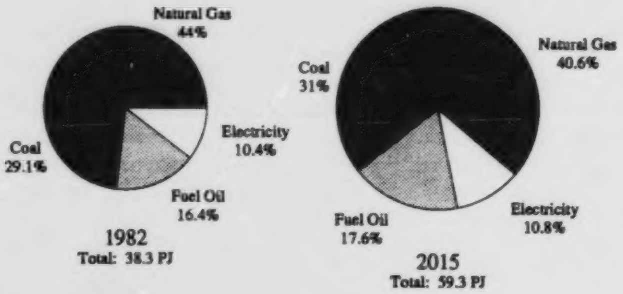
Aluminum smelting and refining is the second largest subgroup of the primary metals industries, following primary steel production. The industry is a major electricity consumer. Reduction of bauxite to alumina has been carried out using the same basic (Bayer) process for almost a century, and only minor efficiency modifications

Figure 9
Cement Industry Energy Demand
Base Case



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

Figure 10
Cement Industry
Energy Fuel Shares



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

may be expected for this process in the future. However, for the reduction of alumina to aluminum, continual improvements in electrode materials and more heat- and power-efficient electrolysis cells will contribute to increased efficiency. Two technological innovations show particular promise: the chloride electrolyte and reduction process, and developments toward direct smelting of aluminum using non-bauxite materials.

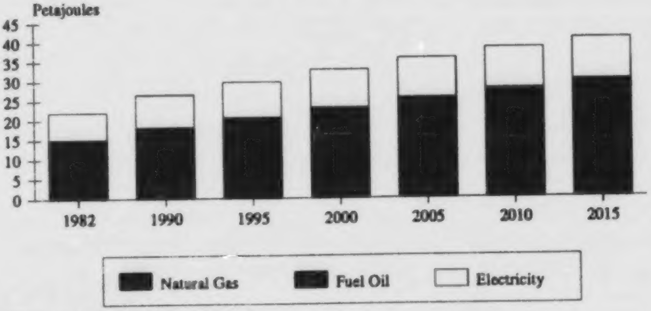
The aluminum smelting industry is another industry where energy demand is slated to undergo substantial growth. At an average annual rate of more than 2.5 percent, total energy demand grows from 22.5 PJ to almost 42 PJ by 2015. Figure 11 shows energy demand growth broken down by energy form. Natural gas has a relatively small share of this total, growing from 0.8 PJ (783 TJ) to 1.5 PJ (1461 TJ) by 2015. The industry is a large user of fuel oil and electricity. Fuel oil consumption doubles from 14 PJ to well above 28 PJ, while electricity use increases from 7 PJ to almost 11 PJ in 2015.

In terms of market shares, natural gas maintains its 3.6 percent share while fuel oil's relative share increases, capturing 5 percentage points from electricity's relative share. These shares are seen in Figure 12.

The fuel oil category is slightly misleading for this industry. Petroleum coke and pitch used as catalyst materials may represent close to half of the refined petroleum products categorized as fuel oil. The forecast was based on a rather conservative assumption of constant petroleum products intensity after year 2000. The MARKAL model of Quebec's aluminum industry indicates that natural gas may penetrate to a market share of 14 to 16 percent by 2005. This penetration would be achieved primarily at the expense of fuel oil demand, excluding catalyst materials.

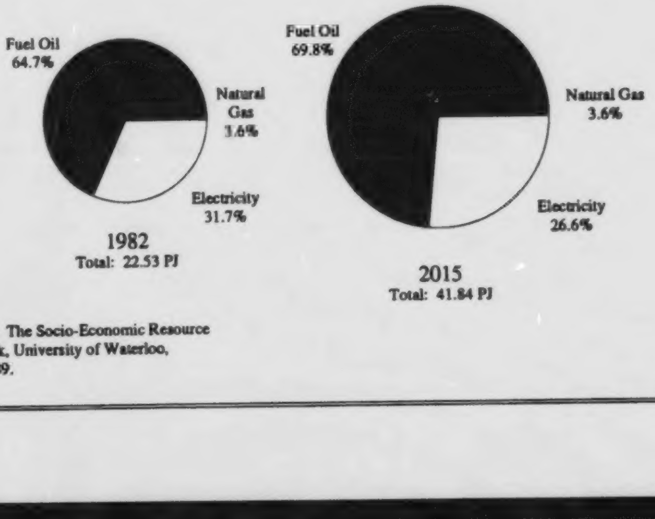
The aluminum industry is traditionally viewed as a captive electricity market of minor concern to the natural gas industry, as these numbers also indicate. However, the research also suggests that a significant natural gas market could potentially be developed in aluminum smelting. Not only should natural gas be able to capture some of the large and growing share of fuel oil, but the advantages of natural gas fired, cogenerated electricity should be explored. The SERF forecasts portray the industry as a growing energy consumer and the current distribution of fuel shares poses a challenge to natural gas.

Figure 11
Aluminum Smelting Energy Demand
Base Case



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Figure 12
Aluminum Smelting
Energy Fuel Shares



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Reference Case Results for the Total Industrial Sector

The total industrial sector is constructed as the sum of all secondary manufacturing and four of the primary production sectors from SERF, namely forestry, construction, mining and primary energy production. This excludes secondary electricity generation, fisheries and agriculture. Recall that the energy demand results do not include energy volumes for non-energy purposes, such as natural gas used as feedstock in the chemical industry and metallurgical coal used in iron and steel production, and furthermore, cover only purchased energy forms.

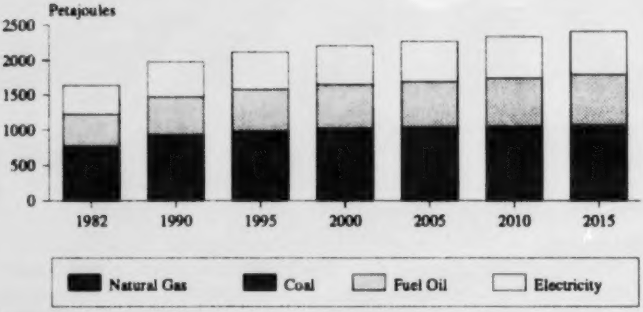
Total energy use in the industrial sector increases by more than 1.4 percent per year, from 1650 PJ in 1982 to 2432 PJ in 2015. Figure 13 illustrates this growth in total energy demand and the demand for the four largest energy carriers. Natural gas demand grows from 723 PJ in 1982 to 996 PJ in 2015, slightly over 1 percent per year.

While demand for all these energy forms is seen to increase in absolute terms, different relative growth rates lead to changes in the relative market shares of each (see Figure 14). The market share of natural gas declines from 44 percent to 41 percent. The market share of fuel oil by comparison increases by almost 3 percentage points. Natural gas demand is predicted to grow more slowly than both electricity and fuel oil, indicating that the competitive pressures on natural gas end-use markets are considerable.

Sensitivity Cases

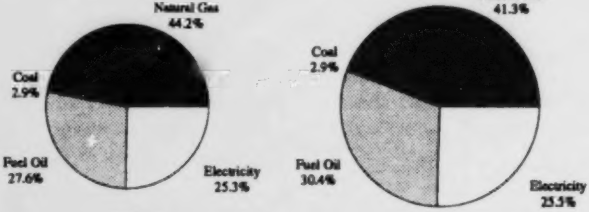
The reference case projections were based on assumptions of fairly steady growth in world oil prices and in industry exports. The base case energy intensities reflected a continued, steady improvement in energy efficiencies as a result of these two sets of assumptions. Two alternative cases were run in the SERF model to explore the sensitivity of the base case results to constant energy intensities of production and stagnant exports, respectively. These sensitivity results are available for all the specific industries considered in the study, but are outlined only for the total industrial sector in this summary.

Figure 13
Total Industrial Energy Demand
Base Case



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Figure 14
Total Industrial Sector
Energy Market Shares



1982
Total: 1649.91 PJ

2015
Total: 2431.57 PJ

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Constant Energy Intensity Case Results

The first sensitivity case was designed to measure the importance of the assumptions regarding energy intensities, reflecting trends in conservation, efficiency and penetration of new technologies. Under this case, energy intensities were left unchanged after 1985 in order to explore the magnitude of the impact these intensity parameter assumptions made on energy demand.

The net effect of this sensitivity case is a significant increase in end-use energy demand over the forecast period. Total energy demand reaches 2733 PJ in 2015, or 301 PJ higher than the base case, representing an annual growth rate of almost 2 percent. Natural gas demand grows to 1189 PJ by 2015, or 193 PJ higher than in the base case.

Stagnant Export Case Results

The reference case assumptions also resulted in a relatively strong primary manufacturing sector, with a trend towards increasing value-added in domestic production. The second SERF sensitivity case was intended to explore the sensitivity of industrial energy demand to a stagnant manufacturing sector. This was achieved by keeping exports from all the industries constant after 1985.

In the stagnant export sensitivity, the relative market shares change in the same pattern as the base case, since the same energy intensities are applied. The magnitude of the changes in demand are even greater for this sensitivity case than for the constant energy intensities case. A stagnant export market leads to energy demand growth of only 0.6 percent per year, for a total of 1970 PJ in 2015, or 461 PJ below the base case. However, natural gas demand of 803 PJ by 2015 indicates that the negative impact of export stagnation, 192 PJ lower than the reference case, is of the same magnitude as the positive impact of constant energy intensities relative to the base case.

Conclusions

The study attempts to convey an idea of the complexities and conflicting trends that underlie the perceived slow changing total industrial demand for energy. The scenario assumptions made for the SERF model represent one possible view of developments in these conflicting industry-specific trends. The numerical results should therefore be treated as illustrations of the impact which these long-term trends could have over a sufficient time period, as opposed to forecasts of actual energy use. The sensitivity cases were also chosen with this objective in mind.

The results of this analysis point to a series of conclusions and recommendations regarding the future role of natural gas in Canada's industrial sector.

Potential Energy Efficiency Improvements

Although demand management and improved energy efficiency have received much attention, there is a lack of comprehensive work illustrating total potential savings in the industrial sector and the impacts on energy use patterns. This report indicates that under a reasonable technology evolution scenario, overall industrial sector energy intensity can decline by around 0.5 percent per year. The reference scenario total energy demand of 4597 PJ is substantially (376 PJ) lower than when energy intensities are left unchanged.

- **Technological changes in production processes can contribute substantially to reducing the growth in total energy demand in the industrial sector.**

The Impact of Efficiency Improvements on Natural Gas Demand

In terms of the impact on individual energy forms, natural gas consumption of 996 PJ in 2015 is 193 PJ lower than if energy intensities are constant for the forecast period. In other words, of the total reduction in energy demand volumes attributed to technological changes in the reference case relative to the constant energy intensity case, more than half comes from reduced natural gas volumes.

- **Although total industrial natural gas demand is growing, new production technologies indicate a particularly high potential for efficiency improvements in natural gas utilization.**

The Link Between Energy and Capital

Both the energy supplier, seeking to maximize sales revenues, and the industrial energy consumer, seeking to produce a competitive product, recognize that energy consumption choices are part of an integrated decision process. Energy consumption is the outcome of capital investment decisions determined within the framework of total productivity, product quality and the working environment. Ultimately the demand for energy in the industrial sector is derived from the demand for the industrial consumers' final product.

- **In view of the potential energy savings demonstrated, industrial energy consumers should strengthen their commitment to energy efficiency improvements, recognizing that energy consumption must be approached in the wider context of capital investment decisions and long-term production goals.**

Promoting Technological Change

From the perspective of natural gas suppliers, these results emphasize the importance of not only understanding but anticipating and developing solutions to their industrial customers' energy needs. In order to retain their market share in an industrial market characterized by intensified inter-fuel competition, with consumers seeking highly energy-efficient technologies, natural gas suppliers should actively support the development and dissemination of such technologies. For example, if natural gas is to retain its share of the shrinking iron and steel reheat market, continued applied research into furnace designs and high efficiency burners must be pursued.

- **Natural gas suppliers should enhance efforts in research and development of efficient natural gas-based production technologies.**

The Role of Advanced Electro-Technologies

The total industrial sector did not display a tendency towards increased penetration of electricity, although the results indicated that some of the most energy-intensive industries, in particular pulp and paper, may experience strong growth in electricity demand. This lack of an overall electrification trend is in itself notable, considering the amount of interest in and the touted potential of advanced electro-technologies. The conclusion that electricity is not likely to increase its relative market share in the industrial sector was based on two premises.

- **To a large extent, the electro-technologies penetrating energy-intensive industries replace less**

efficient electricity-using equipment, leading to a net conservation effect on electricity consumption.

- **Penetration of electricity-using technologies at the expense of thermal-fired equipment is mostly limited to the relatively small, specialized market of high value-added production, which does not have a substantial impact on total industrial energy demand.**

Pursuing Cogeneration Options

In the discussions of electricity intensity in the context of individual industries, cogeneration potential was revealed as a major area of uncertainty. The assumptions specified in the reference case scenario included some penetration of natural gas-fired cogeneration in the high-potential industries, but the technical potential for cogeneration remains largely unexploited. Actual penetration will be a function of financial parameters, such as utilities' buy-back rates and cost of capital equipment. Renewed political emphasis on demand management represents a positive signal in this context.

- **Natural gas suppliers should realize the important potential impact of cogeneration technologies and take an active role in pursuing cogeneration opportunities.**

Recommendations

As Canadian process models become more refined and complete, and providing some modifications and corrections are made to the SERF model, this study may be repeated in the future. SERF remains the only Canadian model with the capability to generate both aggregate and detailed results and respond to such specific assumptions as this study required. An interesting follow-up study may be to provide the regional break-down of industrial energy demand when the SERF data base is regionalized.

Aside from some discussion of cogeneration potential, the question of optimal technology choices for generation of electricity was not considered in this study. The SERF results confirmed that this issue can have a major impact on energy demand.

This study has demonstrated the diversity of energy demand patterns across manufacturing industries and the impact evolving production technologies can have on energy demand. To enhance our understanding of industrial energy demand, it is necessary to commit resources to the upkeep and improvement of the state of process modelling in Canada and to the collection of consistent and meaningful data on energy use by manufacturing industries.

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Preface

Initiated in January 1988, the research for this study was completed in April 1989. A separate Executive Summary of this report is available from the Institute.

The author wishes to thank the five-member Advisory Committee for the direction and constructive criticism provided. Thanks are also extended to the many experts from governments and industries who generously contributed their time and insight. In particular, access to the ISTUM model, granted by Dr. Mark Jaccard with the Natural Resource Management Program at Simon Fraser University, greatly aided the research. Reports provided by the GERAD group at University of Montreal outlining results from the MARKAL model were also of great assistance. ROBBERT Associates ran the SERF model, generating the final study results.

Special thanks are due to a number of the Institute's staff. Garry Sawka contributed valuable research assistance during the summer and fall of 1988, while Susan Wilson assisted in the initial stages of research. Janice Morrison, Beverly Kovacs and Michele Irvin typed numerous drafts. Megan Murphy created the graphics and Vance Lickiss provided computer support. Zaytoon Janjua and Wendy Faid of the I. N. McKinnon Memorial Library gathered source materials from across the continent. Dr. Gerry Angevine, Tony Reinsch and Morgan MacRae provided their support and guidance throughout the project.

Chapter 1

INTRODUCTION

Industrial sector natural gas demand in Canada is characterized by a relatively small number of very large users. From the point of view of utilities and pipeline companies the large and stable baseloads of these industrial customers are crucial to their rate base and to the planning and building of new capacity. For natural gas producers the industrial sector represents the largest end-use market for their product.

Deregulation of natural gas markets and U.S. gas surplus conditions have focussed much attention on the short-term changes in the natural gas market.[1] In the midst of these tumultuous structural changes with many short-term implications, it is important not to lose sight of the fundamental characteristics and conditions for a long-term viable natural gas market. To serve the industrial sector competitively, the producers, marketers and distributors of natural gas must meet the challenge of understanding and anticipating this sector's future energy needs.

This study attempts to outline some key developments on the demand side of the market. Specifically, it provides a comprehensive overview of likely long-term trends in Canadian industrial natural gas demand. Concentrating on the five largest natural gas using manufacturing industries, namely, pulp and paper, iron and steel, petroleum refineries, industrial chemicals and fertilizers, the study provides a detailed description of the industrial processes involved, and thereby an understanding of their energy end-use requirements.

To predict how these energy use patterns will evolve over time, it is necessary to assess the final product demand paths as well as the evolving process technologies for each industry. A number of regional process and end-use models and data bases from across Canada were examined for the purpose of developing such industrial scenarios. A comprehensive, national modelling framework was then employed to forecast long-term natural gas requirements for each of these major industries, and for the entire industrial sector.

1.1 Regional and Sectoral Natural Gas Demand

Energy consumers are commonly divided into three categories or sectors: residential, commercial and industrial, of which the industrial sector is by far the largest. Figure 1.1 illustrates the volume of natural gas consumed in these three sectors for the six provinces that have a well established distribution network.

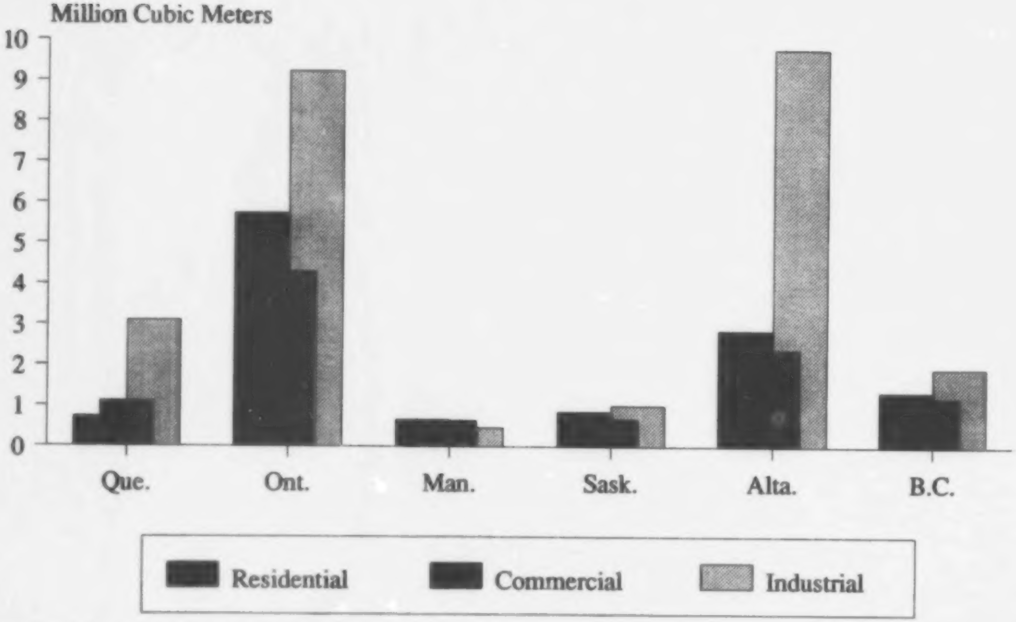
The industrial sector consists of establishments engaged in construction, mining, agriculture and manufacturing. As noted, the number of industrial users is low compared to the number of consumers in the commercial and residential sectors, but the industrial contracts concern large volumes. Within the industrial sector, the manufacturing industries constitute the largest sub-group. Aside from providing an important feedstock for some industries, such as petrochemicals and fertilizers, natural gas has a multitude of process applications as a source of process heat and boiler fuel. Natural gas faces strong interfuel competition in the manufacturing sector, varying in degree according to the specific industrial process and the characteristics of the capital equipment used. Natural gas may compete with distillate and residual fuel oils, coal and electricity, and a host of waste fuels such as refinery gas, coke oven gas, hog fuels and municipal waste.

1.1.1 Large Natural Gas-Using Manufacturing Industries

The Standard Industrial Classification (SIC) code divides manufacturing industries into 22, 2-digit categories, which are then further subdivided into 3- and 4-digit industry sectors. A basic conflict arises in choosing the level of disaggregation for industrial studies. On the one hand, one wishes to cover a significant portion of the market. On the other hand, a detailed exposition requires a fairly homogeneous group and a tremendous amount of data analysis.

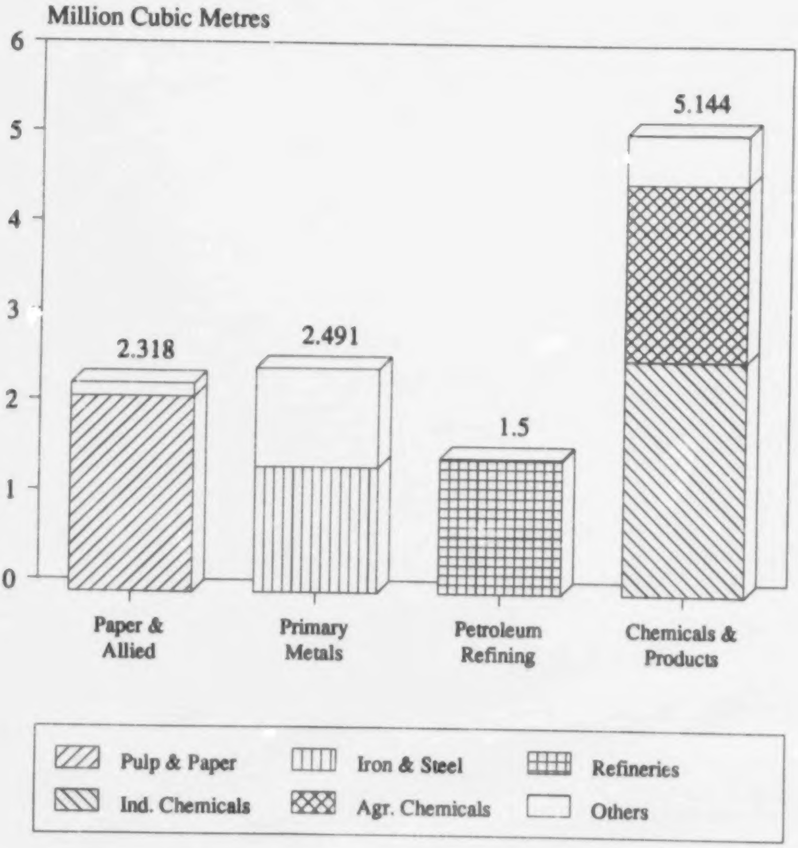
Figure 1.2 illustrates natural gas use in 1984 for four, 2-digit industries and their corresponding largest 3-digit sub-groups. On the national level, these five 3-digit industries, while accounting for less than 20 percent of total manufacturing output, consume 54.3 percent of total purchased energy volumes and 54.4 percent of total natural gas volumes in the manufacturing industries.[2]

Figure 1.1
Regional Natural Gas Sales
1986



Source: Statistics Canada, Catalogue
No. 55-002, December 1986.

Figure 1.2
Major Industrial Natural Gas Users
1984



Source: Statistics Canada, Catalogue No. 57-208, 1984.

1.1.2 Regional Variations in the Industrial Base

There is considerable variation across provinces with respect to the size and composition of the manufacturing sector. Ontario and Quebec clearly constitute the most industrialized provinces in Canada and these provinces also have the most diversified industrial base. In the other provinces, one or two types of manufacturing industries tend to dominate. The Atlantic Provinces currently do not have access to natural gas supplies, and are therefore not considered in this study.

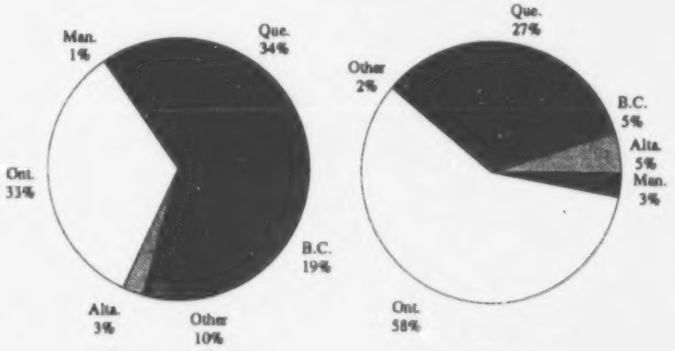
Figure 1.3 illustrates specific regional variations in the industrial base. The numbers represent regional percentage shares of total manufacturing shipments across four, 2-digit energy-intensive industries. For example, 58 percent of Canada's primary metals shipments are manufactured in Ontario, while Ontario and Quebec each produce one-third of all paper and allied products shipments. The prairie provinces capture 25 percent of chemicals production, and Alberta alone represents 21 percent of the petroleum refining shipments. The totals indicate that the provinces specified capture nearly all the industries' shipments, with the exception of petroleum refineries and, to a lesser extent, paper and allied products, where the Atlantic provinces have significant capacity.

Within these industries, natural gas must compete for its share of the total energy consumed. Table 1.1 gives an illustration of the relative shares of fuels and electricity in the volume of total purchased energy for each industry. Note that these figures include only purchased energy excluding, for example, self-generated electricity and hog-fuels. They do not account for fuels for non-energy use, such as natural gas or crude oil feedstocks. Appendix A elaborates on the advantages and limitations of the various available data sources on energy use.

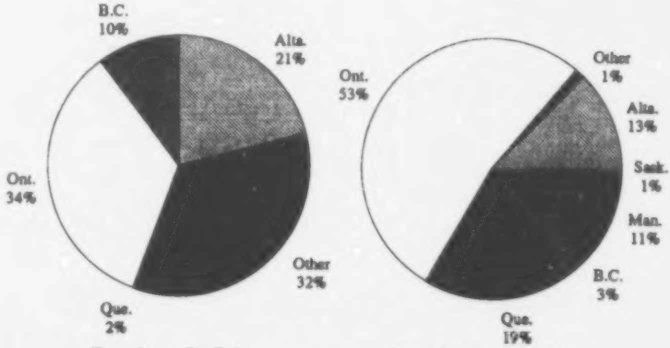
1.1.3 Issues in Industrial Natural Gas Demand

The distinguishing feature of the industrial sector compared to the commercial or residential sectors is that an industry produces a physical product that is sold in a market. This production process requires large inputs of capital, labour, materials and energy. Normally any given product can be produced in a variety of ways using, for example, alternative sources of energy, less total energy and more labour or more highly refined materials. However, at any point in time, a plant is fairly restricted as to specific input requirements for

Figure 1.3
Regional Distribution of Industries by Value of Shipments, 1985



Paper and Allied   Primary Metals



Petroleum Refining   Chemicals and Products

Source: Statistics Canada, Catalogue No. 31-203, 1985.

TABLE 1.1

CONSUMPTION OF PURCHASED FUEL AND ELECTRICITY BY 3-DIGIT SIC CODE INDUSTRIES, 1984

(volumes in terajoules, percentage shares of total energy in brackets below)

	Coal and Coke	Natural Gas	Fuel Oils[a]	Liquified Petroleum Gases	Electricity	Other Fuels[b]	Total Energy Use
Total Manufacturing	37 020 (2.9)	673 071 (52.2)	164 071 (12.6)	8 711 (0.7)	371 306 (28.8)	35 575 (2.8)	1 290 463 (c)
Pulp and Paper	9 400 (3.0)	82 475 (26.2)	88 579 (28.1)	608 (0.2)	133 294 (42.3)	426 (0.2)	314 782 (100)
Primary Steel	12 (–)	52 858 (57.2)	8 892 (9.6)	415 (0.4)	28 897 (31.3)	1 363 (1.5)	92 437 (100)
Petroleum Refineries	–	56 498 (81.1)	79 (0.1)	409 (0.6)	12 573 (18.0)	120 (0.2)	69 679 (100)
Industrial Chemicals	1 000 (0.7)	99 020 (69.7)	5 185 (3.6)	536 (0.4)	36 107 (25.4)	274 (0.2)	142 122 (100)
Agricultural Chemicals	–	75 020 (92.3)	576 (0.7)	24 (–)	5 456 (6.7)	218 (0.3)	81 296 (100)

SOURCE: Statistics Canada, Consumption of Purchased Fuels and Electricity by Manufacturing Industries, Catalogue No. 57-208, Annual (Ottawa: Statistics Canada, 1984).

[a] The sum of light and heavy fuel oil.

[b] The sum of gasoline and diesel. Other energy forms such as kerosene, steam and wood are not reported as volumes, and are therefore excluded.

[c] Percentages do not add to exactly 100 due to compounded rounding errors.

production, given the particular capital equipment in place. The utilization of existing equipment and the investment in new capital depends in turn on the current situation and outlook for the industry's product market. Process technologies are constantly evolving as industries adopt more efficient ways of producing a greater variety of higher quality products.

Future industrial demand for natural gas will therefore depend on several interrelated factors:

- regional outlooks for the individual manufacturing industries;
- changes in each industry's production technologies; and
- natural gas market characteristics and developments.

The performance of Canada's energy-intensive industries depends on macroeconomic developments, such as population growth, inflation and exchange rates. An assessment of the future role of the energy intensive industries in the regional economies will further depend on assumptions regarding structural shifts within the industries or between sectors of the economy. These issues must be addressed in the industry outlooks.

Since both total energy demand and individual fuel shares are closely linked to the capital equipment used in production, technological change is a critical factor to consider in a long-term forecast. In the past, production technologies have been subject to constant change. These changes vary from simple housekeeping measures and retrofits to conserve energy, to the adoption of new processes with new capital equipment and different energy needs, such as cogeneration, electric-arc furnaces and dual-fired boilers. The relative costs and characteristics of energy forms, material and labour requirements, as well as the capital itself, will affect the direction and speed of adoption of new processes.

Finally, continued pursuit of market deregulation will lead to a natural gas market characterized by competitive interaction between buyers and sellers. As the North American gas supply surplus disappears, take-or-pay liabilities are paid off, and regulatory disputes are resolved, a more stable market should emerge.[3] The industrial natural gas market will be at the forefront of these developments in the natural gas market.

1.3 Analyzing Industrial Natural Gas Demand

As capital equipment evolves with changing production technologies, energy efficiency and substitution patterns between energy forms will also change. The aim of producers is to provide their products at a competitive cost and to enhance their market shares. Investment projects with the highest rates of return and projects that enhance product development are not necessarily those that provide the greatest energy savings. There is for many industries a backlog of investment projects that must compete for investment dollars. Capital and labour cost savings are presently of greater overall importance for production cost control than energy savings. To the extent that energy efficiency improvements can be made with short payback periods or through processes that substantially improve product quality or decrease other operating costs, such projects are likely to be implemented.

The type of process changes that can be implemented also depends on the time horizon. In the short term, a number of housekeeping measures, typically high return, low investment projects can be completed. These options have been extensively pursued according to the Canadian Industry Program for Energy Conservation (CIPEC). They generally involve simple retrofits of the existing equipment, load management, scheduling changes, insulation and other efficiency adjustments. In the medium term, more capital intensive retrofits can be undertaken with payback periods of 2 to 4 years. Waste heat recovery through flue gas economizers or steam recovery are typical examples. Such projects may require compressors, heat pumps, heat exchangers and similar capital investments. As equipment is retired, the installation of new, more efficient capital will embody state-of-the-art technologies. However, such complete process changes occur slowly as capital lasts from 10 to 30 years, depending on market conditions and the profitability of new equipment.

With respect to economic activity, it is also important to distinguish between the effect of long- and short-term changes in production levels. In the long run, higher production rates will generally lead to lower energy intensity as new facilities are built. Conversely, a declining industry will display increasing energy use per unit of output as investment is stifled and equipment is operated at less than full capacity.

The short-run effect of changes in production levels may be the exact opposite of the long-run effect, as rapidly rising production may require the start-up of less efficient facilities that had previously been closed down, increasing energy intensity in the short run. Lower capacity requirements would lead to closure of the least efficient plants, increasing the industry's overall energy efficiency. An example of this is the reopening of wet-process cement production facilities in Eastern Canada during a construction boom, allowing for immediate capacity expansion to take advantage of market conditions. If the industry continues to require this capacity, we can expect some of these wet plants to convert to the more efficient dry processes, to the extent that raw material constraints permit.

This underlines the importance of defining the time frame when analyzing energy efficiency. Energy use statistics from any point in time will reflect a mixture of short- and long-term responses to the product market and short- and long-term process changes.

1.2.1 Developments in Total Energy Efficiency

As noted in the data overview in Appendix A, there are some important sources of information on changes in energy efficiency: the Canadian Industry Program for Energy Conservation (CIPEC) reports, the Canadian Energy Audit Program (CEAP) results, and the Ontario Ministry of Energy's Industrial Energy Services Program (IESP). CIPEC reports are available for each of the industries analyzed and will be discussed individually in the industry descriptions. The average goal for all CIPEC's task forces is a reduction of 31 percent in energy intensity by 1990, over the 1973 average base year. Including the 1987 improvements, the reporting industries have achieved a 28.4 percent energy intensity reduction to date.[4] These gains have been categorized by end-use sector. By 1986 the largest gains had been in retrofits (41 percent), followed by housekeeping (28 percent), process changes (19 percent) and product changes (12 percent). The 1986 report also confirmed that most of the potential for short-term changes, such as small retrofits and housekeeping, had been exploited, and that the 1986 improvements primarily involved major one-time changes.[5]

The federal Canadian Energy Audit Program (CEAP) collected a considerable amount of data on potential energy savings before the program was terminated. The data clearly indicates that for the audited companies the largest source of energy savings is in natural gas used in process heat applications. The data base has not been refined to the degree of Ontario's IESP data with respect to end-use categories for individual energy forms.

IESP data is unfortunately not yet available by industrial sector due to confidentiality requirements. The program is offered as a service to industries to help identify potential energy efficiency gains through audits of plants. As of February 1988, 55 audits had been carried out since the inception of the program. The results indicate that process changes yield by far the largest potential energy savings. The most promising process changes were in the area of process heat recovery followed by maintenance, both requiring 2 to 3 years for payback. Changes in electricity use were identified as having the second largest efficiency potential, in terms of dollar savings, mostly through demand charge reductions. For steam use, upgrading steam system equipment and combustion confinement represent large potential savings. When broken out by energy form, natural gas savings offer the greatest dollar potential, but improvements in the use of electricity offer the shortest payback periods, often less than 1 year.[6]

1.2.2 Methodology

The problems of model formulation and data requirements related to long-term forecasts of industrial energy demand are substantial. The various modelling frameworks that have been applied to the analysis of industrial energy demand basically fall into two categories: econometric and end-use models.[7]

1.2.2.1 Econometric Models

Econometrics is the most established modelling technique used in energy demand analysis. Econometric estimation gives values to the parameters in a functional relationship between a dependent and several independent variables, based on the historical correlation between these variables. For forecasting purposes, future estimates of the independent variables will generate a forecast for the dependent variable. The underlying assumption is clearly one of a stable relationship between the variables. Assuming no structural changes (that is, relatively stable prices, a static regulatory environment and no technological change), this framework would perform well. The problem, of course, is that even if we could assume such a stable environment for the future, the data used for the estimation spans an unstable historical period, characterized by energy price shocks and substantial regulatory changes. The estimated parameters therefore reflect an average historical rate of structural change, and it becomes difficult to give meaningful interpretations to these parameters.

Caution must also be exercised in building an econometric model, keeping in mind that the estimation can only measure correlation between variables. It would be a mistake to assume causality based on correlation alone. A solid theoretical framework outlining all the functional relationships and underlying assumptions is required so that the model, not the statistical correlation, explains the relationships between variables.

Econometric models have been used to estimate and forecast industrial energy demand at various levels, including total industrial, total manufacturing or 2-digit industries, for national, regional and provincial data. One can estimate the demand for a single fuel or for all competing energy forms simultaneously. One of the most general and sophisticated econometric models for the industrial sector is the translog cost function, which has been estimated repeatedly in Canada for various industries and regions.[8] This model allows for substitution between the aggregate inputs (capital, labour, material and energy), and between the various energy forms. A dynamic specification in the form of lagged adjustments in capital is also possible within such an econometric model.[9]

The advantages of econometrics are obvious. The models are relatively small and the data requirements therefore limited, although it must be kept in mind that the quality of the data must be high for meaningful results and that a consistent time series is required for each variable. The models are easy to run and are well established. Given good data and a well specified model, good short- to medium-term forecasts can quickly and easily be generated.

The problems, however, are equally obvious. First, as already pointed out, there is no inherent reason why an historical average trend should form the appropriate basis for future developments. The slow changing nature of industries is often cited as a supporting rationale, mitigating significant structural change. However, significant changes have taken place in the last 15 years. Clearly, for long-run forecasting purposes, econometrics is of limited use. Furthermore, the industrial sector is dominated by a relatively small number of large energy users, so that the data will tend to vary erratically in response to changes related to one of the users. For example, a new pulp mill in Alberta will lead to a large jump in energy use in that sector. Overall trends are therefore difficult to estimate and even harder to interpret.

1.2.2.2 End-Use Models

As the name suggests, these models concentrate on the processes that actually use the energy. End-use categories are defined within specific production processes such as boilers, furnaces, drying or motive power. The physical transformation of materials and energy in these processes is simulated in a model. These models can vary from fairly simple input-output frameworks to sophisticated, optimizing, dynamic programming models. An optimizing model can, for example, choose the most cost-effective production process, given capital and other input costs and a projected product demand path.

The amount of modelling work and the detail of the data required for this type of model is the main disadvantage of this approach. Providing an accurate description of total energy demand for the industrial sector clearly requires a monumental effort. On the other hand, this level of detail is only required for a picture of the present state of existing operations, so that a long, consistent time series is not needed.[10] The problem of verification of end-use models remains hard to solve. With so many exogenous input parameters and coefficients, errors may cancel each other out. While a set of parameters may generate excellent results over a backcast verification period, the results for a forecast period may be poor if variables fall in a different range of values.

1.3 Study Objectives and Outline

The intent of this study is to investigate in detail the factors affecting energy use in Canada's most energy-intensive industries, and to provide a long-term forecast for natural gas use in the industrial sector. Because of the required detail and the long-term aspect of the forecast, a description of the capital equipment in use and a discussion of technological change for these industries has been included.

This need for industry and process-specific detail conflicts with the desire for a total industrial natural gas demand forecast. The forecast effort was further complicated by the need to take into account inter-industry connections and shifts in this dependency structure in the long term, as well as other structural shifts affecting the industrial sector. For example, if the pulp mills change their technology to predominantly chemi-thermo mechanical pulping, this will have implications for the chemical industry which supplies the required chemicals.

An econometric methodology was not deemed suitable for this task, as econometrics cannot adequately model or forecast long-term structural change, and there are significant problems involved in constructing a consistent time series of data. A number of process and end-use models from across Canada were examined and the results and sensitivities of these models provided the basis for detailed, process-specific industry outlooks. These outlooks take the form of industry scenarios containing energy intensities of production.

In order to take into account all inter-industry dependencies, prospects for product exports, and domestic demographic developments, the industrial activity levels were calculated using the Socio-Economic Resource Framework (SERF) at the University of Waterloo. Appendix C provides an overview of the structure of SERF. The manufacturing sector is represented in the model by complete input-output matrices, so that all the inter-industry flows of goods are included when total production is calculated. Furthermore, the specified energy intensity parameters reflect penetration of future production technologies yielding natural gas demand results for each of the energy-intensive industries and from the goods producing sector in total, taking into account the effect of an evolving capital stock.

Chapters 2 through 5 provide descriptions of the selected energy-intensive manufacturing industries. A great deal of process and energy end-use detail is provided in the descriptions. These chapters provide perspectives for the product demand and technological change projections developed in Chapter 6 as industry scenarios. The results of the SERF simulations and study conclusions are reported in Chapter 7, focussing on the projections for industrial natural gas demand and the sensitivity of natural gas use to changes in scenario assumptions.

In addition, a number of appendices are included. Appendix A gives an overview and evaluation of the data sources available in Canada for energy use analysis. Appendix B provides short descriptions of the end-use and process models that have been considered, while Appendix C presents the SERF modelling framework in greater detail. Finally, Appendix D presents the detailed energy demand results by industrial sector and energy form for the 1982 to 2015 forecast period.

Footnotes

[1] For an historical exposition of the development of the infrastructure and regulatory framework of Canada's natural gas markets see: Andre Plourde, Oil and Gas in Canada: A Chronology of Important Developments, 1941-1986, Energy Study No. 86-5 (Toronto: Policy and Economic Analysis Program, Institute for Policy Analysis, University of Toronto, November 1986).

[2] Canada, Statistics Canada, Manufacturing Industries of Canada, National and Provincial Areas, Catalogue No. 31-203 for GDP data, and Consumption of Purchased Fuels and Electricity, Catalogue No. 57-208 for energy use data (Ottawa: Statistics Canada, 1988).

[3] For a complete discussion of the characteristics of and developments in the North American natural gas market see: Kevin Brown, Towards a Continental Natural Gas Market: Historical Perspectives and Long-Term Outlook, Study No. 26 (Calgary: Canadian Energy Research Institute, April 1988).

[4] Canadian Industry Program for Energy Conservation, Task Force Report 1987 (Ottawa: Department of Energy, Mines and Resources, 1987).

[5] Canadian Industry Program for Energy Conservation, Task Force Reports 1986 (Ottawa: Department of Energy, Mines and Resources, 1986).

[6] Ontario, Ministry of Energy, Industrial Energy Services Program (Toronto: October 1987).

[7] For a discussion of methodologies, see: Mark Jaccard, An End-Use Energy Demand Forecast Model for the Industrial Sector: Case Study of the French Pulp and Paper Industry, Principal arguments and conclusions of doctoral thesis (Grenoble: Institut Economique et Juridique de l'Energie, 1987).

[8] The bibliography contains a series of references to papers using the translog cost function to estimate industrial energy demand, see for example: Berndt, Fuss and Waverman, 1977; DataMetrics, 1978; Fuss, 1977; McRae, 1978 and 1981; and McRae and Webster, 1978 and 1982.

[9] E. R. Berndt, M. Fuss and L. Waverman, Dynamic Models of the Industrial Demand for Energy, Electric Power Research Institute EA-580, Project 683-1, Interim Report (Palo Alto, California: EPRI, November 1977).

[10] F. D. Gault, R. B. Hoffman, and B. C. McInnis, "The Path to Process Data," Futures, October 1985.

Chapter 2

THE PULP AND PAPER INDUSTRY

The pulp and paper sector, SIC code 271, is the largest 3-digit sub-group of the paper and allied products industries. The industry produces a wide variety of products: wood pulp, newsprint, paper and buildingboard, book and printing papers, tissue and sanitary papers, wrapping papers and building papers. By far the two largest product groups are woodpulp and newsprint, each representing in excess of 38 percent of total physical shipments.[1] Paperboard represented approximately 10 percent of shipment tonnes and book and printing paper 4 percent in 1985. Shipments exceeded 23 million tonnes in 1985 with a total value of $13,470 million.[2]

2.1 The Size and Significance of Canada's Pulp and Paper Industry

The industry is of importance both in the national and international economy. It represented approximately 3 percent of Gross National Product (GNP) and over 8 percent of total Canadian exports in 1985. More than 75 percent of the Canadian production is exported, and Canada accounts for approximately 15 percent of world pulp production and 32 percent of newsprint production. Because domestic consumption is so low compared to production, Canadian exports as a percentage of world exports are even more significant, representing 32 percent of world wood pulp exports and 63 percent of world newsprint exports.[3]

The bulk of Canadian exports, almost 70 percent in 1985,[4] are destined for the U.S. market. Although U.S. demand is still growing, Canadian exports face increasing competitive pressure from U.S. domestic producers. U.S. self-sufficiency, particularly in high quality mechanical pulp, is rising. However, most of this production expansion is taking place in the South, and a corresponding proportional fall in production in the North Central region will probably leave Canada with a sufficient competitive advantage in the North to at least retain its U.S. market share.[5] Other important markets are: Western Europe, receiving approximately 9 percent of Canadian exports; Japan, close to 6 percent; and the U.K. at just under 4 percent in 1985.[6] Japan has been a major growth market in the past, but future market expansion is limited by the growing Japanese domestic paper industry which is based on recycled fibres. An important market potential is seen in the growing demand from Pacific Rim countries, although Canada has to compete increasingly against expanding production from high yield forests in Latin America and other developing countries.

Compared to other resource-based industries, Canada's pulp and paper sector weathered the 1982-1983 economic downturn well. The capacity utilization of the paper and allied products industry fell to 73.3 percent in 1982, but has since climbed steadily to average 97.7 percent in 1987.[7]

2.2 Factors Determining the Regional Supply of Pulp and Paper

The most important determinants of pulp and paper production are the cost and availability of raw materials, the location of these material supplies relative to the product markets, and the associated transportation costs.

2.2.1 Raw Material Requirements

The main raw materials required to produce pulp are the cellulose fibres of wood. The choice of pulping process determines the quality and characteristics of the pulp produced, and the need for specific pulp qualities ultimately depends on the type of paper product to be produced. Different pulping methods also have very different yields, ranging from 45 to 95 percent of usable dry fibres derived from dry wood.[8] The minimum allowable cut necessary to sustain a pulp mill will therefore vary considerably with the pulping process used.

Table 2.1 illustrates the location of Canada's wood resources, explaining why the pulp industry is located mainly in B.C., Ontario and Quebec. The numbers represent merchantable timber on economically accessible forest land.

TABLE 2.1

TOTAL FOREST VOLUME BY REGION, 1981 MERCHANTABLE TIMBER

Region	Million Cubic Metres
Atlantic	1214
Quebec	4133
Ontario	3198
Prairie	2556
B.C.	7842

SOURCE: The Canadian Pulp and Paper Association, 1986 Reference Tables (Montreal: CPPA, 1987), Table 10, p. 10.

Quebec still has large fibre reserves, but much of the remaining fibre is becoming only marginally accessible, limiting the potential for an expansion of the industry. Alberta has a substantial unexploited potential, possessing more than 56 percent of the reserves of the Prairie region. The Alberta government is interested in exploiting this potential to increase diversification of the province's industrial base and to spur economic activity.[9]

The pulp and paper industry has been classified as a large energy user but, for this industry in particular, it is important to distinguish between purchased and self-produced, and primary and secondary energy use. A great deal of the energy required for pulp and paper making can be produced from process by-products such as wood wastes and black pulping liquor. Furthermore, the primary energy forms, whether purchased or self-produced, are extensively used to produce secondary energy. Section 3.4 provides more detail regarding the energy flows and requirements for specific processes.

Depending on the process chosen, an array of chemicals may be required by a mill. Chemicals are used mainly in digestion of wood chips to pulp, and for pulp bleaching. Clean water is also required in large volumes, ranging from 12 to 113 cubic metres per tonne of pulp depending on the process.[10] Clean water requirements may effectively limit the choice of sites for a mill. Recovery and recycling of chemicals and water, extracting heat and effluents, have greatly reduced requirements of new chemicals and clean, cold water.

2.2.2 Transportation Costs

Since the cost of transporting round wood is relatively high, the supply of pulp from a region is closely related to the supply of wood. While pulp can be transported in dehydrated form, the cost of transporting paper can be high, particularly if small quantities have to be transported to a number of different destinations. This is often the case for high quality, specialty papers. Such paper mills will therefore tend to be located near major population centres. Bulk paper, such as newsprint, is more often produced in an integrated pulp and paper mill located close to the forest reserves. This trend may change in the future with new production technologies, as discussed in Section 2.4.4.4.

Table 2.2 illustrates the preponderance of mills in Quebec, Ontario and B.C. It also shows the higher concentration of separate pulp mills in B.C., producing mostly chemical pulps, and being more heavily integrated with the lumber industry than with paper production. This is in contrast to the more integrated pulp and paper operations of Central Canada, where the emphasis is on newsprint production.

TABLE 2.2

MILL LOCATIONS, 1985

	Pulp Mills	Pulp and Paper Mills	Paper Mills	Total
Atlantic	6	11	1	18
Quebec	8	35	14	57
Ontario	3	19	14	36
Prairie	3	--	1	3
B.C.	14	8	2	24
Total	34	75	33	142

SOURCE: The Canadian Pulp and Paper Association, 1986 Reference Tables (Montreal: CPPA, 1987), Table 5, p. 6.

2.3 The Production Process

The breakdown of a fully integrated pulp and paper operation would consist of the following steps:

- Raw material harvest, collection and transportation,
- Wood preparation; debarking and chipping,
- Pulping,

- Bleaching,
- Pulp stock preparation,
- Sheet formation,
- Pressing,
- Drying, and
- Finishing; coating, cutting and binding.

More generally, we can divide the process into two stages: pulping, encompassing the first four steps; and paper making, consisting of the last five. Figure 2.1 illustrates how these steps vary through the different processes.

Mechanical pulp can be produced directly from roundwood or from chips, whereas chemical pulps require wood chips. The chemical recovery cycle is also unique to chemical pulping. These processes result in various pulp grades which can be mixed and bleached as required. The steps in paper making are the same for all pulps, but the degree of processing required at any step will differ depending on the final product.

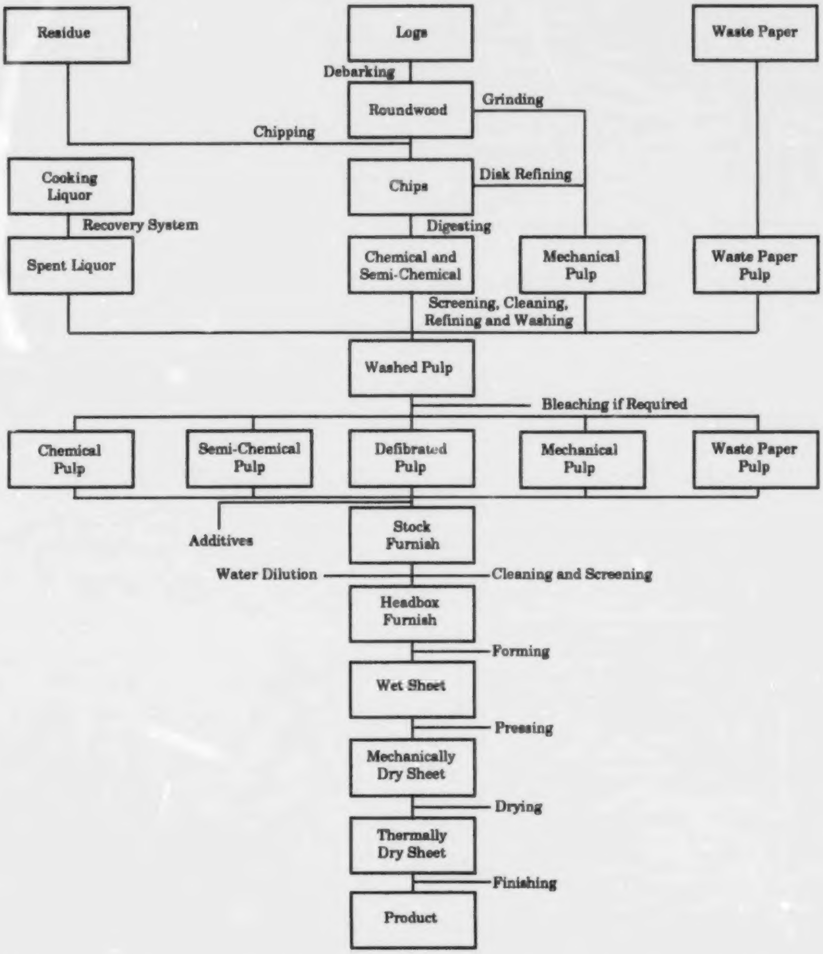
Paper can be made from a variety of pulp grades and often consists of a combination of pulps. As noted, pulp can be treated as a separate product to be marketed to domestic or foreign paper mills, or the two processes can be integrated, transforming wood to the final paper product on site.

2.3.1 The Pulping Process

Pulping wood involves disintegrating lignin, the compound that binds wood fibres together, to produce the cellulose fibre mass called pulp. This may be done mechanically or with the aid of chemicals, heat and pressure to produce various grades of pulp. In general, softwood will produce a longer fibre pulp of higher strength, whereas hardwood provides a shorter fibre with greater opacity and better sheet formation qualities. However, these qualities are also dependent on the pulping process used.

The yield of a pulping process depends on whether the lignin is dissolved or retained in the pulp mass. Yield is defined as the weight of dry, usable fibres that are derived from a given weight of dry wood, expressed as a percentage. Table 2.3 illustrates the variation in yield between various pulping methods.

Figure 2.1
Basic Operations in Paper Manufacture


Residue
Logs
Waste Paper
Debarking
Roundwood
Grinding
Chipping
Cooking Liquor
Chips
Disk Refining
Recovery System
Digesting
Spent Liquor
Chemical and Semi-Chemical
Mechanical Pulp
Waste Paper Pulp
Screening, Cleaning, Refining and Washing
Washed Pulp
Bleaching if Required
Chemical Pulp
Semi-Chemical Pulp
Defibrated Pulp
Mechanical Pulp
Waste Paper Pulp
Additives
Stock Furnish
Water Dilution
Cleaning and Screening
Headbox Furnish
Forming
Wet Sheet
Pressing
Mechanically Dry Sheet
Drying
Thermally Dry Sheet
Finishing
Product

SOURCE: Electric Power Research Institute, EA-3507, Vol. 2, 1984, p. 2-9.

TABLE 2.3

YIELDS OF PULPING METHODS

Pulping Method	Percent
Mechanical Pulps	95
Chemi-Mechanical Pulps	90
Semi-Chemical Pulps	75
Unbleached Chemical Pulps	50-55
Bleached Chemical	45-50

SOURCE: D. Baillard; C. Berger; A. Haurie; R. Loulou; and H. Simonsen, Modelling Energy Technology in the Pulp and Paper Industry of Canada: The Markal Approach, Les Cahiers du GERAD, Ecoles de Hautes Etudies Commerciales, Affiliee a l'Universite de Montreal (Montreal: Group d'Etudes et de Recherche en Analyse des Decisions, January 1987).

Yields are lower if more chemicals are used in the process, since chemicals will dissolve the lignin and absorb it in the spent pulping liquor. This is why chemical pulps are also referred to as wood-free pulps.

2.3.1.1 Chemical Pulping

The chemical process of kraft pulping is one of the most widely used in Canada, constituting 81 percent of all chemical pulps and 48 percent of total pulp production in 1985.[11] The raw timber is debarked and cut to wood chips, and the chips are then dissolved in a heated chemical solution of sodium sulphate, referred to as white pulping liquor. The spent or black pulping liquor contains a mixture of sodium sulphate and lignin, which can be recycled with around 85 percent chemical recovery. The evaporated and compressed black liquor is sprayed into the recovery boiler where the organic components are burnt off, producing smelt. The dissolved smelt is referred to as green pulping liquor. The lime kiln transforms the green liquor from the recovery boiler to white, reusable pulping liquor by adding the required alkali for effluent neutralization and make-up of liquor losses.

Depending on the desired characteristics of the final product, kraft pulp can be bleached to a high degree of brightness. Traditionally chlorine or chlorine compounds are used for this, but new bleaching techniques and catalysts to increase efficiency, improve product quality and lessen environmental impact are under continual development.

Other chemical processes include the use of acidic bisulphate and sulphur dioxide. The process steps are the same as for kraft pulping, but the pulp is of lower quality and chemical recovery is also lower. Semi-chemical pulping can use either sulphite or sulphate as a dissolving agent. Wood chips are partially softened with steam pressure and chemicals before being ground mechanically.

2.3.1.2 Mechanical Pulping

Instead of soaking wood chips in chemical solutions, pulp can be produced by mechanical grinding and shredding. Logs can be ground against a revolving stone producing stoneground wood pulp (SGW), or chips can be shredded and ground between rotating disks to produce refiner mechanical pulp (RMP). If mechanical pulp is produced under elevated pressure, it is called pressurized ground wood (PGW). The mechanically produced pulp mass is of a lighter colour than chemical pulp and requires less bleaching, but the abrasive method leads to shorter pulp fibres, hence a lower quality pulp. Mechanical pulp is used to manufacture newsprint, a bulk product that does not require strength and durability. The process requires a high proportion of specific input fibres such as debarked, softwood chips. Almost 95 percent of the wood biomass becomes pulp, since the lignin is ground up rather than dissolved. Mechanical pulp is produced mostly in integrated mills.

Recent technological advancements include the development of thermo-mechanical pulping (TMP) and chemi-thermo mechanical pulping (CTMP). In the TMP process, the wood chips are softened by heat and broken apart by high pressure blowing. CTMP is produced by adding small amounts of chemicals to this process in order to modify the properties of the pulp. These methods produce a long fibre pulp that can be used for paper with superior printability, strength and absorbency. They are also less capital intensive than the chemical processes, but require substantially more purchased energy, particularly electricity. The process yields fewer waste products that can provide process heat and fuel for self-generation of power.

2.3.1.3 Recycled Fibres

Although of limited importance in Canada today, the recycling of fibres will become a more pertinent issue as environmental concerns, including problems of waste disposal and of resource limitations, exert increasing pressures. Secondary fibres can be used to varying degrees in practically all paper and board grades, but the main uses are for newsprint and corrugated multiply boards. Recovered mechanical pulp is very important from an energy efficiency standpoint, as the electric power requirement for pulping is less than 20 percent that of virgin pulp. However, the quality of secondary pulp is inferior to virgin pulp, setting limits to its use. In addition, recycled pulp does not contribute fuel for process steam production, so that the amount of recycled fibres used also depends on the energy balance of the specific mill. The waste fibres must be mechanically cleaned from impurities such as plastic or iron materials and printing ink must also be removed.[12]

2.3.2 Paper Making

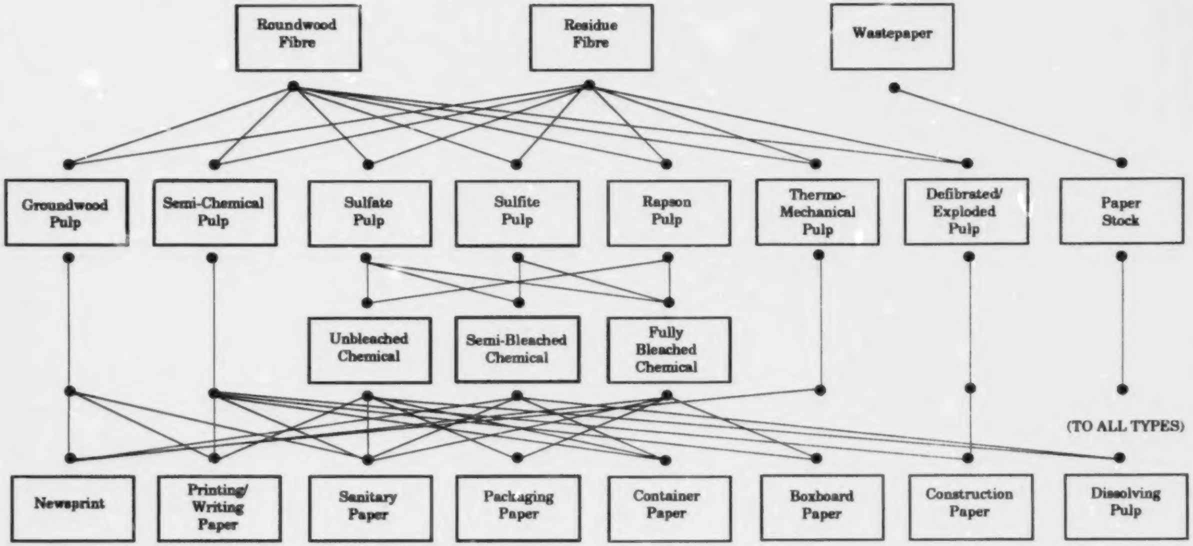
Various paper products are produced from different pulp grades or a mixture of pulps. Newsprint generally consists of 90 percent or more mechanical pulp. Magazine papers can be 50-50 mechanical and chemical pulps with high filler contents. Kraft bags and sacks, on the other hand, come from 100 percent unbleached kraft pulps.[13] Figure 2.2 illustrates this relationship between pulp and paper grades.

Pulp enters the paper making process in liquid form, as slush pulp, with 3 to 4 percent pulp consistency. It goes to the refiners where it is beaten in order to plasticize and fragment the fibres and fray the fibre surfaces. The importance of this process varies between products; for example, very little beating is required for tissue paper from mechanical pulps, a great deal more for kraft papers. The slush pulp is then further diluted to 1 percent pulp consistency before it is screened and thickened. The fibres are suspended on a finely woven screen to form a mat, and water is removed by suction, vacuum and draining, increasing the dry content to 20 percent. This mat is passed through presses and dryers. In the press section water is removed until a dry content of 35 to 45 percent is achieved.

Paper drying is the most energy-intensive process in paper making, as heat is applied by blowing or drum drying to evaporate remaining water, yielding up to 95 percent dry content. Pressing can be up to five times as energy efficient, but over-pressing can damage the paper, setting limits to the substitutability between processes. The heat content from the wet air above dryers can be recovered.

Finally, the paper is subject to finishing processes such as cutting, splitting, binding and coating. Coating treatment adds substantially to energy use as the paper has to be dried twice. Coating

Figure 2.2
Relationship Between Fibres, Pulps and Papers


Roundwood Fibre
Residue Fibre
Wastepaper
Groundwood Pulp
Semi-Chemical Pulp
Sulfate Pulp
Sulfite Pulp
Rapson Pulp
Thermo-Mechanical Pulp
Defibrated/ Exploded Pulp
Paper Stock
Unbleached Chemical
Semi-Bleached Chemical
Fully Bleached Chemical
(TO ALL TYPES)
Newsprint
Printing/ Writing Paper
Sanitary Paper
Packaging Paper
Container Paper
Boxboard Paper
Construction Paper
Dissolving Pulp

SOURCE: Electric Power Research Institute, EA-3507, Vol. 2, 1984, p. 4-3.

materials such as china clay or other pigments may be used. Starch and starch derivatives can be added in the drying section to increase paper strength and aid the retention of fibres. Likewise, titanium dioxide may be added to increase opacity.

2.4 Energy Use in Pulp and Paper Production

The preceding sections have attempted to convey an appreciation of the wide variety of conditions that prevail from mill to mill and between regions. This section will track the energy flow through the stages in pulp and paper making and comment on changes in total energy intensities and potential technological changes that could affect end-use demand for specific energy forms.

2.4.1 Energy Flows and End-Use of Energy

Direct, high temperature flame heat is required for lime burning in the recalcination kiln, flash drying of paper, and high intensity hoods on paper machines. In addition, a great deal of thermal energy is used for boiler operation, producing large amounts of steam. Steam can be used to run turbines generating electricity, as well as for process heat. Low- and medium-pressure steam can also be recovered from electricity generation and used for process purposes.

Process steam is required for cooking and bleaching pulp, evaporation of waste liquor in the recovery cycle, and pulp and paper drying. Drying is traditionally accomplished by steam rolling, but new electrical blowers are penetrating this market. Electricity is used in machinery such as pumps, fans, blowers and agitators and in various transportation systems, but the largest use of electricity is for mechanical pulp grinding.

Table 2.4 demonstrates the wide variations in electricity, steam and direct heat requirements between pulping processes. Note that these numbers represent only final energy requirements; the actual energy use is much higher. For example, the direct fuel column does not include fuel required to generate steam, and steam use does not include steam required to generate electricity. It is also important to be aware that the numbers are average and approximate and that mill to mill variations may be substantial depending on the mix of products produced and the age of the equipment. For an individual mill, however, both the process heat and the electricity requirements are stable, since operation levels are normally high and continuous.

TABLE 2.4

ENERGY COEFFICIENTS FOR PULPING PROCESSES

Pulping Processes	Process Electricity (kW.h/t)	Direct Steam (GJ/t)	Direct Fuel (GJ/t)
Stoneground Wood (SGW)	1200	--	--
Refiner Mechanical Pulp (RMP)	1400	--	--
Thermomechanical Pulp (TMP)	2200	--	--
Chemi-thermomechanical Pulp (CTMP)	1836	2.6	--
Low Yield Sulphite (LYS)	85	6.5	--
High Yield Sulphite (HYS)	425	4.0	--
Neutral Sulphite Semi-chemical (NSSC)	500	5.3	--
Ultra High Yield Sulphite (UHYS)	1325	2.6	--
Unbleached Kraft (UBK)	100	15.1	2.7
Semi-bleached Kraft (SBK)	325	18.8	2.7
Bleached Kraft (BK)	555	18.8	2.7
Bleached Sulphite (BS)	450	6.1	--
Defibrated and Exploded (DEX)	200	1.7	--
Recycled (REC)	420	1.2	--

SOURCE: D. Baillard; C. Berger; A. Haurie; R. Loulou; and H. Simonsen, Modelling Energy Technology in the Pulp and Paper Industry of Canada: The Markal Approach, Les Cahiers du GERAD, Ecoles de Hautes Etudies Commerciales, Affiliee a l'Universite de Montreal (Montreal: Group d'Etudes et de Recherche en Analyse des Decisions, January 1987), Table A.1.1, p. 51.

As Table 2.4 shows, the mechanical processes require the largest amounts of electricity, since the grinders are electrically driven. With the TMP and CTMP processes, electricity use is dramatically increased from 1200 to 2200 kW.h/t. The degree of energy self-sufficiency in a mechanical mill is also much lower because the electricity and steam balances are less suited for cogeneration, and the availability of waste products for boiler fuel is lower. Chemical pulping, on the other hand, requires the highest amounts of process steam. Kraft pulping is especially steam intensive, and it is the only process with direct fuel requirements due to the lime kiln in the chemical recovery cycle.

For the paper products produced from pulp, Table 2.5 indicates smaller differences in energy requirements between products.

TABLE 2.5

ENERGY REQUIREMENTS FOR PAPER PRODUCTION FROM SLUSH PULP

	Electricity (kW.h/tonne)	Steam (GJ/tonne)
Newsprint	540	6.0
Groundwood Specialties	545	8.6
Book and Writing Papers	450	7.6
Kraft Papers	510	7.8
Linerboards	370	6.0
Boxboard	510	8.3
Tissue and Sanitary Papers	930	7.2
Building Board	250	8.0

SOURCE: D. Baillard; C. Berger; A. Haurie; R. Loulou; and H. Simonsen, Modelling Energy Technology in the Pulp and Paper Industry of Canada: The Markal Approach, Les Cahiers du GERAD, Ecoles de Hautes Etudies Commerciales, Affiliee a l'Universite de Montreal (Montreal: Group d'Etudes et de Recherche en Analyse des Decisions, January 1987).

The total energy required for a specific paper product becomes the weighted average of energy use for each pulp in the specific pulp combination required, plus the paper product requirements from Table 2.5 above.

Tables 2.4 and 2.5 have illustrated the total end-use requirements for energy. Since most of the steam and, depending on the process, a large portion of the electricity may be generated from other fuels, a very different energy use picture transpires when looking at input energy. Table 2.6 shows the shares of each energy form as a percentage of total primary energy inputs. These shares are presented for the two largest product groups in the pulp and paper industry, bleached kraft pulp and newsprint with integrated production of sulphite pulp. Note that input energy includes self-produced energy forms such as hog fuels and self-generated hydro electricity, but excludes energy produced from other energy sources, such as electricity or steam generated from natural gas.

TABLE 2.6

INPUT ENERGY AS A PERCENT SHARE OF TOTAL ENERGY, 1984

Fuel Type	Bleached Kraft Pulp Mill	Integrated Newsprint Mill
Purchased Electricity	3.4	46.1
Natural Gas	11.2	11.2
Residual Oil	6.6	15.0
Distillates and LPG	0.4	2.0
Coal and Coke	1.7	3.7
Hog Fuels	18.5	16.3
Pulping Liquors	57.8	1.0
Self Generated Hydro	0.4	4.7
Total Energy Intensity (GJ/tonne)	44.9	19.4

SOURCE: CERI sample of CPPA database.[14]

The most striking feature of Table 2.6 is the degree of energy self-sufficiency in kraft mills. To place this in perspective, consider that kraft pulping is more than twice as energy intensive, requiring 44.9 GJ/tonne, compared to integrated newsprint manufacturing, requiring only 19.4 GJ/tonne. However, in terms of purchased energy, the production of newsprint becomes the more energy intensive, with 15.1 versus 10.4 GJ/tonne for bleached kraft pulp.[15] With respect to individual fuel use, newsprint production accounts for the bulk of the purchased electricity. Both processes purchase the same percentage share of natural gas, but because total energy requirements are so much higher for kraft pulp, natural gas volumes are proportionately higher as well.

This high degree of self-sufficiency is also evident from a comparison with Table 1.1 which showed energy shares for purchased energy only. Electricity had a share of 42 percent, and natural gas and fuel oil, 26 and 28 percent, respectively, of total purchased energy.

2.4.2 Changing Energy Efficiency

There is no theoretical minimum energy requirement for paper production, since the energy content of the raw materials is greater than that of paper. Such theoretical minimum requirements can be calculated based on the first and second laws of thermodynamics. More realistically, model plant calculations measuring the minimum energy inputs required to operate the most efficient equipment available confirm that the pulp and paper industry can be a net producer of energy for external use.[16]

The Pulp and Paper Industry Task Force of the Canadian Industry Program for Energy Conservation (CIPEC) reported total energy savings of 33.1 percent in 1987 over the 1972 base year. The goal of 33.3 percent improvement in energy efficiency by 1990 is almost reached. CIPEC efficiency calculations relate physical output only to purchased energy and the index is corrected for changes in product and raw material mix and quality, weather and regulatory changes. Although the efficiency calculations do not include the use of waste fuels, CIPEC's observations confirm the trend of increasing substitution of waste fuels for purchased energy, reporting that waste fuels and captive hydraulic power accounted for 57 percent of total energy use in 1987. The pulp and paper industry's participation in CIPEC is exceptionally high, covering 98 percent of production.[17]

CERI's Study No. 23 on the pulp and paper industry[18] confirms the overall decline in input energy per unit product, even when self-produced fuels are taken into account. This downward trend is most pronounced when the energy intensity of the various fuels is adjusted for by using a Btu index. The substitution away from high-cost, purchased fuels, particularly residual fuel oil, and the increased use of waste fuels were also noted. The combination of these trends accounts for the substantial fall in purchased energy as calculated by CIPEC.

The other important trend in energy use in the pulp and paper sector has been the increase in purchased electricity. For integrated newsprint mills, CERI calculated an increase in the share of purchased electricity from 34.7 percent of total energy in 1972 to 46.1 percent in 1984, with particularly large jumps between 1982 and 1984, rising from 40.8 percent in 1982. This trend is caused by a number of factors. As seen, the electricity use is concentrated in mechanical pulp and in integrated newsprint mills, and therefore in Eastern Canada. The increase in TMP capacity from 620 air dried tonnes (ADt)/day in 1975 to 13 906 ADt/day by 1988 contributes to higher electricity use.[19] Technological change has also favoured some substitution away from steam and towards electricity use by implementing heat recovery systems, and by increased pressing rather than drying of paper.

Hydro Quebec's Industrial Boiler Conversion Program has been a major influence on energy use in Quebec. The subsidized installation of electric boilers, combined with the sale of very cheap, surplus power, gave a large boost to electricity consumption. It has been estimated that the program led to displacement of one-third of Quebec's total heavy fuel oil demand in 1985, and that the pulp and paper industry absorbed the largest impact of this program.[20]

For the integrated newsprint mills sample, the increase in electricity use was matched by a fall in residual fuel oil's share from 33.0 percent in 1972 to 15 percent in 1984, with particularly large declines in the last 2 years of the data series, falling from 26.2 percent since 1982. The natural gas share, on the other hand, increased in 1984; its share growing 1.8 percentage points to 11.2 percent. This reversal of the previously declining trend was a signal that industries have sought to diversify their energy supply options.

For the bleached kraft pulp mill sample, the energy shares have been more stable. A 0.5 percent increase in electricity use to 4.3 percent in 1984 was caused by boiler electricity demand in one of the four eastern mills, as a result of Hydro Quebec's program. The only discernible trend is the decline in residual fuel oil from 13.6 percent in 1972 to 6.6 percent in 1984, and a concurrent increase in hog fuels from 12.1 percent to 18.5 percent and in pulping liquor from 55.3 percent to 57.8 percent.[21]

2.4.3 Cogeneration

Cogeneration is defined as the simultaneous production of process heat and electricity. Since the energy flow in a pulp and paper mill consists primarily of steam and electricity, this industry represents a large theoretical potential for cogeneration. Energy cascading studies have also focussed on cogeneration where, in addition to process heat and electricity requirements, excess or secondary heat is recovered and used for district heating.[22] If the pulp and paper industry is to continue on its path towards self-sufficiency, or indeed, become a net producer of energy, this will have to be achieved through increased implementation of cogeneration. Linear programming simulations of the U.S. pulp and paper industry have shown that the price of electricity has little effect on total electricity demand, but it can substantially affect the division between purchased and self-generated electricity.[23]

The cogeneration system most often discussed for the pulp and paper industry is the steam turbine, fired with wood wastes and natural gas. There is a wide range of estimates of cogeneration potential and it is important to recognize the substantial gap between the amount of cogeneration that is technically feasible, and the amount that is likely to be installed. While regulatory policies, energy prices, capital costs, and risk perceptions have no impact on the theoretical potential, they can make a substantial difference to how much cogeneration is actually implemented.

CERI's conclusions regarding cogeneration potential in Study No. 24 also emphasize the regional variations.[24] Ontario was identified as having the greatest potential of around 1000 additional MW, with 500 MW already installed. Quebec also showed high technical potential, but the availability of inexpensive electricity and the province's political emphasis on small hydro developments made implementation less likely. Saskatchewan and Manitoba have, according to provincial studies, limited potential for cogeneration. Alberta was identified as having the greatest potential among the western provinces, but this is presumably in the chemical and petroleum refining industries, as the pulp and paper mills are already largely energy self-sufficient. In B.C. the capacity was at that time perceived as being largely exploited unless buy-back rates were substantially increased.

Since the release of this CERI study, there has been a shift in policy emphasis both in B.C. and Ontario, increasing the importance of demand side management and exploring the demand options, in particular with respect to electricity. These changes signal an increased openness to accommodate and encourage cogeneration facilities, improving the potential for implementation.

A recent study commissioned by the Ontario Ministry of Energy estimates that the greatest potential, 22 percent or 301 MW of the total cogeneration capacity likely to be implemented, is in the pulp and paper industry. The total potential, likely to be developed before the year 2000, is estimated to be 1347 MW. This entire potential lies in the industrial sector.[25] The sensitivity results of this study indicate that the electricity price is the largest implementation incentive, but lower payback period requirements will also quickly eliminate the potential. Previous studies have estimated a range of industrial potential from 150 to 1500 MW of additional implementable capacity.[26]

2.4.4 Technological Change in Pulp and Paper Making

Aside from the maintenance, process control, equipment upgrading and heat recovery developments that are an ongoing effort, there are a number of long-term, more fundamental process changes which carry implications for the future choice of energy forms and for total energy use.

With respect to product characteristics and market developments, chemical pulps have the quality advantage of high brightness and strength. Unlike mechanical pulps, chemical pulps will not turn yellow over time since they are wood-free. The new mechanical processes, TMP and CTMP, also produce high strength pulp, but with present technologies this pulp cannot be bleached to the brightness required for fine printing papers. The expected penetration of CTMP, replacing kraft as well as mechanical processes, has therefore not been realized to date.

The limits to process substitution are presently clear, although new bleaching compounds and techniques may increase the future penetration of CTMP. The development of new chemicals for bleaching indicate movement away from chlorine and chlorine compounds to, for example, hydrogen peroxide. Oxygen bleaching has also become an established technology. New paper making processes such as multi-ply web forming will also allow greater penetration of CTMP, as CTMP or TMP pulp can be included as a middle layer, with kraft pulp on either side, for high surface brightness and retarded yellowing.

Although a growing market is expected for fine, coated papers, Canadian mills have a transportation disadvantage with respect to the pure mineral pigments required for coating. These pigments are currently imported from Georgia, U.S.A., but Saskatchewan and B.C. may have a potential to supply such pigments. This could potentially increase the competitive position of Canadian mills and allow them to develop a market niche for a high quality, highly refined product. An alternative is increased use of synthetic polymers as fillers and pigments, an area presently under research.

2.4.4.1 Technological Change In Chemical Pulping

A number of new process technologies have been proven, and are currently being adopted by chemical pulp mills. These include continuous rather than batch kraft cooking in a high heat washing system, leading to improved productivity and decreased water requirements. Traditional batch systems have also been improved. For pulp bleaching, oxygen blowing is well established and serves to decrease both energy and chemical use. Improved catalysts for oxygen bleaching are also under continual research. Displacement bleaching has the potential to lower both steam and electricity intensity by 65 and 57 percent, respectively. This technology is expected to be implemented gradually over the next two decades.[27]

The processes and energy balances of the proposed third kraft mill in Alberta, the Daishowa mill at Peace River, provides an example of the degree of energy self-sufficiency, waste recovery and utilization possible in a state-of-the-art plant. The plant will produce 321 400 ADt/year of kraft pulp, 240 000 ADt from aspen hardwood and 81 400 ADt from spruce softwoods, in a continuous digester system. The pulp stock will be oxygenated to require less bleaching. This reduces water requirements to 75 m^3/ADt of bleached pulp, substantially below the typical kraft plant requirements of 113 m^3/ADt.[28]

Total steam generation from the power and recovery boilers combined will be 6.8 tonnes steam/ADt (18.7 GJ/ADt). The recovery boiler will burn strong black liquor and approximately 30 percent natural gas, while the power boiler will run mainly on waste woods with natural gas as start-up and back-up fuel. The lime kiln will be the largest natural gas user, bringing total consumption to 4.8 Mcf/ADt (5.06 GJ/ADt).

Total electricity use is estimated to average 38 MW which, based on continual 350 day operation per year, represents 993 kW.h/ADt. The size of this number compared to the typical 555 kW.h/ADt reported in Table 2.4 is probably due to the on-site bleach plant. Total primary energy requirements can be broken down to 20 percent hog fuels, 64 percent black liquor, 15 percent purchased natural gas, and 1 percent purchased electricity. Note that the share of waste fuels (84 percent) is considerably higher than the average 76.3

percent reported in Table 2.6. A steam turbine generator substantially satisfies the mill's power requirements. The plant has modern effluent treatment including scrubbers, dust collectors, polishers for condensate return, etc.[29]

The most revolutionary technological changes could potentially take place in the chemical recovery cycle. Much research is presently directed towards gasification of black liquor. The Champion International gasification system transforms black liquor to green liquor and heating gas. This partial combustion releases energy for process use and increases both the efficiency and the safety of recovery. The recausticizing part of the cycle is retained.

Plasma gasification does away with the entire causticizing unit. The plasma basically augments the burning, leading to very high temperatures. The method does not enhance energy efficiency, as a significant volume of electricity is required, while energy is recoverable only as low grade heat. However, the capital savings resulting from elimination of the causticizing section may outweigh the increased energy cost and the cost of plasma. Assessing the impact of such technological change is difficult, since the energy balances of individual mills are unique. The following example is, therefore, included only for illustrative purposes.

The proposal for the Daishowa kraft mill at Peace River includes a lime kiln estimated to burn approximately 2.23 GJ natural gas per tonne pulp. This represents more than 40 percent of the mill's projected natural gas use. In addition, the recovery boiler, although designed to burn black liquor, will require natural gas for back-up and start-up periods. In total, natural gas requirements for the causticizing unit may come close to 45 percent of the kraft mill's natural gas use, and this direct heat market for natural gas would be threatened if plasma technology penetrated. The increased demand for electricity may represent a potential market for a higher degree of self-generation or cogeneration of electricity, but these electricity needs can be met by burning the decomposed organic gases from the plasma gasification process in a conventional boiler to produce steam and electricity.

Economic development of this technology in North America is not predicted to be substantial for the forecast period of this study, due to the size of investment and operating costs involved, and because full-scale testing is still not completed.[30]

Several alternatives to the traditional evaporation of black liquor also exist. Membrane separation processes such as reverse osmosis and ultrafiltration represent established technologies. The advantage lies in a high degree of concentration of the liquor, but the electricity required to raise the pressure of the liquor sufficiently against the membrane makes it a costly alternative. It has been implemented in Canada in the case of very high quality effluents. Freeze concentration has the same disadvantage of high energy requirements and energy inefficiency in the refrigeration cycle. A Mechanical Vapor Recompression (MVR) system can replace a section of the traditional evaporator system, decreasing steam and increasing electricity use. The economics of all such alternative evaporation systems are highly site-specific and sensitive to steam, electricity and capital cost variations.[31]

Natural gas is also likely to encounter increased competition from coal and waste fuels. Traditionally natural gas has been the preferred limekiln fuel due to its clear burning characteristics, but improved filtration techniques enhance the competitive standing of other fuels for lime calcination.

2.4.4.2 Technological Change in Mechanical Pulping

The development of pressurized groundwood pulping represented a breakthrough in mechanical pulping technologies, in that the sealing and pressurizing of the grinders produced a very opaque pulp, stronger than SGW but not as strong as TMP or CTMP. The increased capital costs can be offset by up to 10 percent lower electricity use. Developments in TMP and CTMP have led to potential increases in energy efficiency through steam recovery. From the mechanical energy and pressure of the grinders, heat is dissipated through water to steam. Recovery of steam from the refiner disk shafts can recapture approximately 80 to 90 percent of the electrical energy used for grinding. The steam can then be used for process water heating, paper drying, mill space and district heating.

Paper drying has been the most attractive alternative, especially for newsprint paper machines. In the TMP process, 75 percent of the recovered steam can be used for paper drying. Steam recovery is aided by heat exchangers and high pressure cyclones that separate organic materials from the steam. These types of developments may explain the relatively slow implementation of heat pumps in the industrial sector. The value of steam recovery varies with the value of thermal energy. If boiler fuels are expensive, steam can become a very valuable product. The amount of energy that can be recovered also depends on the refiner pressure and consistency.

Considerable research has been carried out in development of heat pump technology. Paprican is exploring the possibilities of a steam generating, high-temperature heat pump (HTHP) in newsprint mills with freon-R114 or -R113, and subsequent upgrading of the steam produced by mechanical or thermal vapour recompression.[32] Currently, these technology options have an estimated pay-back period ranging from approximately 3 to 6 years, but again, the economics are highly site specific and dependent on relative energy prices.[33]

There is little doubt that TMP and CTMP will continue to penetrate mechanical pulping processes. With CTMP's ability to produce high quality pulp from hardwoods such as aspen, production costs can be lowered by the increased availability of fibre. Peroxide bleaching brings CTMP pulp to 80 percent brightness, allowing substitution for chemical pulp in newsprint pulp mixes.

2.4.4.3 Other Pulping Technologies

Medium consistency pulping, keeping the pulp at 8 to 15 percent fibre consistency, is a process development that holds substantial promise of reduced production costs through large reductions in capital costs, less pollution, and lower water requirements. Above about 8 percent consistency, pulp mass appears solid. Pumping pulp has, therefore, traditionally been carried out at 1 to 6 percent consistency. This has necessitated repeated dilution and thickening of the pulp mass for transportation and processing. By using shear forces creating turbulence, medium consistency pulp can be transported through oxygen bleaching, washing, chlorination bleaching, screening, pumping and storage systems.[34]

Another development in pulping technologies is alcohol pulping (organosolv), which involves cooking the chips in a solution of ethyl or methyl alcohol. The great advantage of alcohol pulping lies in the recovery of pure lignin, a highly valued adhesive. One organosolv plant is presently operating in New Brunswick.[35] A more esoteric area of research is biological pulping, making use of bacterial or fungal decomposition of wood to fibres. Commercial application of this method is severely hampered by the time required for decomposition, and by the storage and handling problems implicit in the process.

2.4.4.4 Technological Change in Paper Making

The traditional Fourdrinier wire, the screen on which the pulp is suspended at the wet end of the paper machine, has the drawback of draining water from the slush pulp only from one side of the mat. This sets production limits and will affect paper quality as the top and bottom surfaces develop different characteristics. The development of a twin wire, or single wires applied to both sides in sequence, has led to more uniform, higher quality products and higher production speed. At the wet end of the paper machine, improved presses, such as the extended nip (Beloit) press, can minimize the use of more energy-intensive dryers.

In the calender stack, developments are aimed at improving paper qualities through thickness reduction, increased smoothness and glossiness. For the highest quality papers, an off-machine super calender is used. Because of the inherent inefficiencies in off-machine processes, developments have been made that improve on-machine calendering. Soft calendering substitutes plastic or rubber for the usual steel rolls. Hot and temperature-gradient calendering leads to plasticizing of surface fibre by heating the rolls to high temperatures.

New paper machines are becoming increasingly flexible, allowing multiple grades of fine, specialty paper to be produced in an integrated mill. These machines produce a variety of high, consistent qualities of paper at higher speed in a continuous mode, reducing or eliminating the need for off-machine calendering. The grade characteristics of the paper can be changed by adjusting the machine settings without interrupting the process.

In paper drying, there has been a trend away from thermal drying and towards increased electricity use, associated with increased use of presses and blow drying rather than steam-heated drum drying. The introduction of radiant wave or induction technology represents a more radical process change. This technology enables the producer to exercise a high degree of control over location, penetration and quantity of heat applied to a product. The shorter wavelengths, such as micro and radiowaves, penetrate deeper, leading to higher uniformity of absorption. Infrared (I-R) waves are longer and lead to higher energy absorption near the surface. For paper making, I-R drying can therefore give increased surface quality and moisture retention as well as low moisture variability.

I-R heaters can run on either natural gas or electricity. Electric I-R heaters have the advantage of less scrapage and quicker on-off response. I-R heaters can be applied at either the wet or the dry end of the paper machine. Where the dryer represents a bottleneck in the production process, an I-R heater can increase the speed of production. For coating drying, requiring only surface treatment, the I-R dryer has shown promising potential.

Impulse drying is defined as the simultaneous application of mechanical pressure and high intensity heat. This is a very promising process, producing high surface density. The application of impulse drying is particularly likely for heavy paper grades, allowing weaker pulps to produce stronger products.

For paper drying, special chemical heat pumps using sodium hydroxide in an absorption drier process also represent a potential technology. A pay-back period as low as 2.7 years has been estimated for a full-scale plant. It is considered a competitive option if sufficient waste steam, at only slightly above atmospheric pressure, is available. Where steam upgrading needs are limited, a conventional thermocompressor can be utilized.[36]

2.5 Conclusions

The potential technological developments in chemical pulping are seen to be concentrated in the recovery cycle. For mechanical pulps, TMP and CTMP with steam recovery and increasing use of hardwood can replace the traditional stoneground wood and some of the chemical pulp used in mixed pulps, particularly for newsprint production. This leaves a core market for kraft pulp aimed at high quality, fine paper products. Hot and temperature gradient calendering is likely to be implemented through the 1990s, and electromagnetic technologies, in particular heaters, will probably be concentrated in dryer-limited production situations and for high quality products. Impulse drying, on the other hand, has the greatest potential for packaging grades.

Combustion technologies are also under going constant developments. Power boilers and auxiliary equipment for burning waste fuels have tackled problems of high or variable moisture content in the hog fuel, sludge, continuous fuel feeding and ash removal systems. The commercial viability of such technologies, coupled with stricter environmental regulations regarding alternative disposal of hog fuels, can be expected to further enhance the productive use of waste fuels in pulp and paper production.[37]

Footnotes

[1] Total shipments include shipments of pulp to Canadian destinations for domestic paper production. As a result, there is a certain amount of duplication in this figure. It does not represent the value added of total production, but rather the full value of market pulp added to the full value of final paper products.

[2] The Canadian Pulp and Paper Association, 1986 Reference Tables (Montreal: CPPA, 1987).

[3] Ibid.

[4] Ibid.

[5] Brookhaven National Laboratory, Industrial Process Models of Electricity Demand, Vol. 2: The Pulp and Paper Industry, EA-3507, Project 1762-1, Final Report (Palo Alto, California: Electric Power Research Institute, May 1984).

[6] CPPA.

[7] Canada, Department of Regional Industrial Expansion, Rate of Capacity Utilization, 4th Quarter 1987 (Ottawa: Supply and Services, 1988).

[8] D. Baillard; C. Berger; A. Haurie; R. Loulou; and H. Simonsen, Modelling Energy Technology in the Pulp and Paper Industry of Canada: The Markal Approach, Les Cahiers du GERAD, Ecoles de Hautes Etudies Commerciales, Affiliee a l'Universite de Montreal, Montreal: Group d'Etudes et de Recherche en Analyse des Decisions, January 1987).

[9] For example, Daishowa has proposed to build a third kraft pulp mill at Peace River, see footnote 28.

[10] Baillard et al, p. 8, calculate that 12 m^3 water per tonne pulp is typically required for the TMP and CTMP processes, 113 m^3 water per tonne for bleached kraft pulp.

[11] CPPA.

[12] Sixten Olof Regestad, Energy Consumption in Industrial Processes: Pulp and Paper, Working group 6, 13th Congress of the World Energy Conference (Cannes; October 5-11, 1986).

[13] Ibid.

[14] CPPA's database contains 25 bleached kraft mills and 26 integrated newsprint mills. CERI's Study No. 23 was based on a sample of this database of 15 bleached kraft and 19 newsprint mills. Exclusions were based on inadequate reporting or cases where a mill produced a large number of products.

[15] Ellen Battle, Energy Efficiency in Canada's Pulp and Paper Industry, CERI Study No. 23 (Calgary: Canadian Energy Research Institute, 1986), p. 58.

[16] Battelle Columbus Laboratories, Evaluation of the Technical Potential for Energy Conservation in Seven Basic Industries. Report prepared for U.S. Federal Energy Administration Reproduced by National Technical Information Service (Columbus, Ohio: Battelle Columbus Laboratories, July 1975), p. 22.

[17] Canadian Industry Program for Energy Conservation, Task Force Reports 1987 (Ottawa: Energy, Mines and Resources, 1986).

[18] E. Battle, 1986.

[19] Tonnes are measured as air dried tonnes (ADt). As the weight of pulp depends on the water content, it is important to indicate the degree of dryness in production figures.

[20] G. A. Robb Associates Energy Consultants, The Impact of the Hydro Quebec Electric Boiler Program on Industrial Energy Statistics. A study for Energy, Mines and Resources Canada (Ottawa: G. A. Robb Associates, March 1987).

[21] E. Battle, 1986.

[22] Canada, Department of Energy, Mines and Resources, Conservation and Renewable Energy Branch, Development of An Energy Cascading Plan for a Typical Canadian Industrial Community. Industry Series Publication no. 4. (Ottawa: Energy, Mines and Resources, December 1982).

[23] For a complete discussion of cogeneration systems and implementational constraints, see: Anthony E. Reinsch and Ellen F. Battle, Industrial Cogeneration In Canada: Prospects and Perspectives. Study No. 24. (Calgary: Canadian Energy Research Institute, March 1987).

[24] Ibid., p. 104.

[25] Acres International Ltd., Cogeneration Potential in Ontario and Barriers to its Developments, report prepared for the Ontario Ministry of Energy (Toronto: Ontario Ministry of Energy, February 1987).

[26] Ibid., p. 9, Table 1-2.

[27] P. F. McArdle and P. L. Wilkinson, "Industrial Sector Energy Analysis: The Paper Industry," Gas Energy Review, vol. 16, no. 8, p. 4.

[28] See Footnote 19.

[29] H. A. Simons Ltd., Environmental Assessment Report, Peace River Kraft Pulp Mill, prepared for Diashowa Canada Ltd. for submission to Alberta Environment December 1987, Revised January 4, 1988.

[30] Temanex Consulting Inc., Technoeconomic Trends Favouring Increased Electrical Demand by the Pulp and Paper Industry - A Status Report. Report for Canadian Electrical Association (Montreal: Canadian Electrical Association, October 1987), p. 60.

[31] Ibid., pp. 66 and 67.

[32] R. L. Douglas Cane, Ontario Research Foundation, Industrial Heat Pump Technology Review. Report prepared for Ontario Ministry of Energy, Energy Technology Development (Toronto: Ontario Ministry of Energy, June 29, 1987).

[33] CIPEC, 1986, p. 62.

[34] Temanex Consulting Inc., 1987, p. 97.

[35] Frank Bohlken, Forecasting Energy Demand in the B.C. Pulp and Paper Sector Using the ISTUM End-Use Model, Research project for the degree of Master of Natural Resource Management, Report No. 67 (Burnaby: Simon Fraser University, August 1988).

[36] Acres International Ltd., Chemical Heat Pump "Phase A" Study, Report produced for the National Research Council of Canada, NRCC No. 25182 (Ottawa: National Research Council of Canada, March 1985).

[37] W. M. Newby & Associates Limited, Large Scale Combustion Technology for Steam Production. A report produced for the National Research Council and Energy, Mines and Resources, NRC #18732 (Ottawa: National Research Council, November 1980).

Chapter 3

THE IRON AND STEEL INDUSTRY

Within the primary metals sector, the iron and steel mills, SIC code 291, represent the largest single category both in terms of shipments and energy use. The value of purchased fuels and electricity for raw steel manufacture in 1986 exceeded $501 million, with raw steel representing 45 percent of total primary metal shipments.[1] Total raw steel production in 1987 exceeded 14.7 million tonnes, up 4.5 percent from almost 14.1 million tonnes in 1986.[2] The major product groups of finished shapes are: rails, structural shapes, bars, rods, wire and wire products, pipe, tubes, plates and sheets and strip. Hot rolled and cold reduced sheets and strip constituted close to 40 percent of total steel shipments (including semi-finished shapes) in 1987, followed by plates (including plates for pipes and tubes) and bars, each accounting for close to 20 percent.[3]

3.1 The Size and Significance of Canada's Iron and Steel Industry

On a national basis, the iron and steel industry accounted for 0.5 percent of GDP and 3.2 percent of total manufacturing output in 1987. Canadian capacity utilization has climbed steadily from a low of 50.4 percent in the third quarter of 1982 to an average of 83.5 percent in 1987. This recovery has been aided by rationalization of capacity. Total production capacity in January 1987 was 18.6 million tonnes, down from over 20 million tonnes in 1986.[4]

Total exports of crude steel in equivalent steel ingots was 3.75 million tonnes in 1986 and exceeded 3.0 million tonnes over the first 9 months of 1987.[5] The U.S. is by far the most important export market, receiving in excess of 80 percent of total exports. Developments in the U.S. market are therefore of great importance to Canadian producers.

The U.S. integrated iron and steel industry is generally older and still operates a larger proportion of less productive equipment such as open hearth furnaces. As part of a U.S. federal initiative to improve the industry's productivity, the Voluntary Restraint Agreement (VRA) was negotiated in 1984. The VRA places limits on imports to protect the U.S. industry and allow time for restructuring and modernization. Significant efforts are also being made in the area of research, development and demonstrations of new technologies.[6]

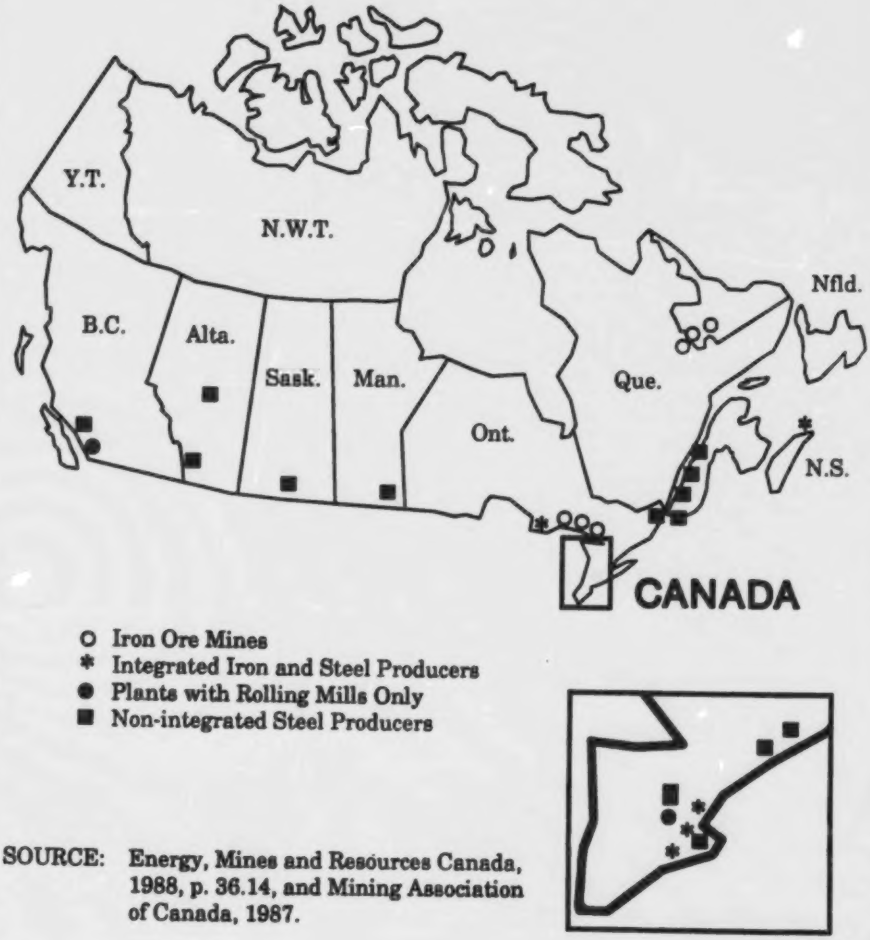
The VRA was individually signed by countries exporting steel to the U.S. to avoid accusations of dumping and subsidizing steel. Canada was not required to sign the VRA, but Canadian producers have agreed informally to maintaining their current U.S. market share of 3 to 3.5 percent in order not to aggravate the protectionist pressures in the U.S. Unless the VRA is extended and signed again, its expiration at the end of 1989 can only benefit Canada, easing the pressure on the domestic market and allowing expansion of exports. This would be further solidified by the Free Trade Agreement.

The world oversupply situation is expected to be remedied by further rationalization of capacity by the mid- to late-1990s. Although there has been a shift in productive capacity from OECD countries to Eastern Europe, Asia and South America, and this development is expected to continue, the lower volumes produced in the West still generate the same level of revenues. This is due to higher degrees of product refining as OECD countries manufacture higher value added products. The outlook for the industry is therefore fairly good, provided the efforts to increase productivity and product quality are continued. The industry has undertaken major upgrading programs, with capital expenditures on construction and machinery of $439.4 million in 1985, $786.3 million in 1986 and a preliminary estimate of $1016.6 million in 1987.[7]

3.2 Regional Iron and Steel Production

Commercial deposits of iron ore, availability of coking coal and scrap, and proximity to major markets are the important factors determining the location of iron and steel mills. Figure 3.1 illustrates the important Canadian ore deposits and iron and steel mills by degree of integration. The three largest integrated producers (Stelco, Algoma and Dofasco) are all located in Ontario, making Ontario the focus of Canadian iron and steel production. The industry accounted for close to 8 percent of that province's manufacturing output in 1986,[8] compared to the 3 percent national average. Dofasco is now in the process of taking a majority interest in Algoma, consolidating the industry into two major producers, both marketing a wide range of products.[9] Dofasco is the largest producer of flat rolled products, particularly aimed at the automotive and consumer durable industries. Algoma, on the other hand, produces a variety of capital goods and is a major supplier to the energy sector. Algoma was therefore particularly hard

Figure 3.1
Iron and Steel in Canada
1987


Y.T.
N.W.T.
B.C.
Alta.
Sask.
Man.
Ont.
Que.
Nfld.
N.S.
CANADA
○ Iron Ore Mines
* Integrated Iron and Steel Producers
● Plants with Rolling Mills Only
■ Non-integrated Steel Producers

SOURCE: Energy, Mines and Resources Canada, 1988, p. 36.14, and Mining Association of Canada, 1987.

hit by the declining and stagnant oil prices of the mid-1980s, while Dofasco has prospered as a result of the construction boom and growth in the domestic automotive industry, and has been able to expand into high value products.[10]

In addition to these large, fully integrated companies producing finished products from iron ore, a large number of smaller producers exist serving specialized, downstream market niches. Many of these base their production on recycling scrap or produce only semi-finished shapes to be rolled into final products in separate finishing mills. Such smaller producers exist in most provinces, but as Figure 3.1 and Table 3.1 indicate, production is concentrated in Ontario and Quebec.

TABLE 3.1

RAW STEEL CAPABILITY IN CANADA
1986

	Number of Mills	Tonnes of Ingots and Castings
Nova Scotia	1	502 700
Quebec	18	2 415 010
Ontario	26	12 842 540
Manitoba	2	354 050
Saskatchewan	1	685 000
Alberta	5	398 450
British Columbia	5	199 000
Total	58	17 396 750

SOURCES: Statistics Canada, Primary Metal Industries 1986, Catalogue No. 41-290B, Annual (Ottawa: Statistics Canada, Industry Division, 1987) and Department of Energy, Mines and Resources, Metallurgical Works in Canada, Primary Iron and Steel 1987, Mineral Bulletin MR 214 (Ottawa: Supply and Services, 1987), pp. 28-29.

3.3 The Production Process

In a fully integrated iron and steel mill, the production process can be broken down into the following five steps:

- Preparation of Raw Materials: Coke, Ore and Limestone,
- Pig Iron Production,
- Crude Steel Production,

- Production of Semi-Finished Products: Blooms, Billets and Slabs, and

- Production of Final Products.

Figure 3.2 illustrates the process of transforming raw materials to final steel products. The alternative production routes and the specific equipment involved are the topics for this process overview.

Unlike most other primary manufacturing sectors, the steel industry bases substantial production on recycled scrap. Prepared scrap is introduced at the crude steel production stage, varying from 25 to 35 percent of the charge in a basic oxygen furnace to a maximum of 100 percent in an electric arc furnace. Steel making from scrap may therefore preclude the first two stages of the process. Many plants are also exclusively involved in the last stage of production, converting semi-finished to final products.

3.3.1 Raw Materials for Steel Making

The first stage in steel making concerns preparation of iron ore, coke and limestone for the blast furnace. This can take place at the mine site, but many mills handle their own raw material preparation.

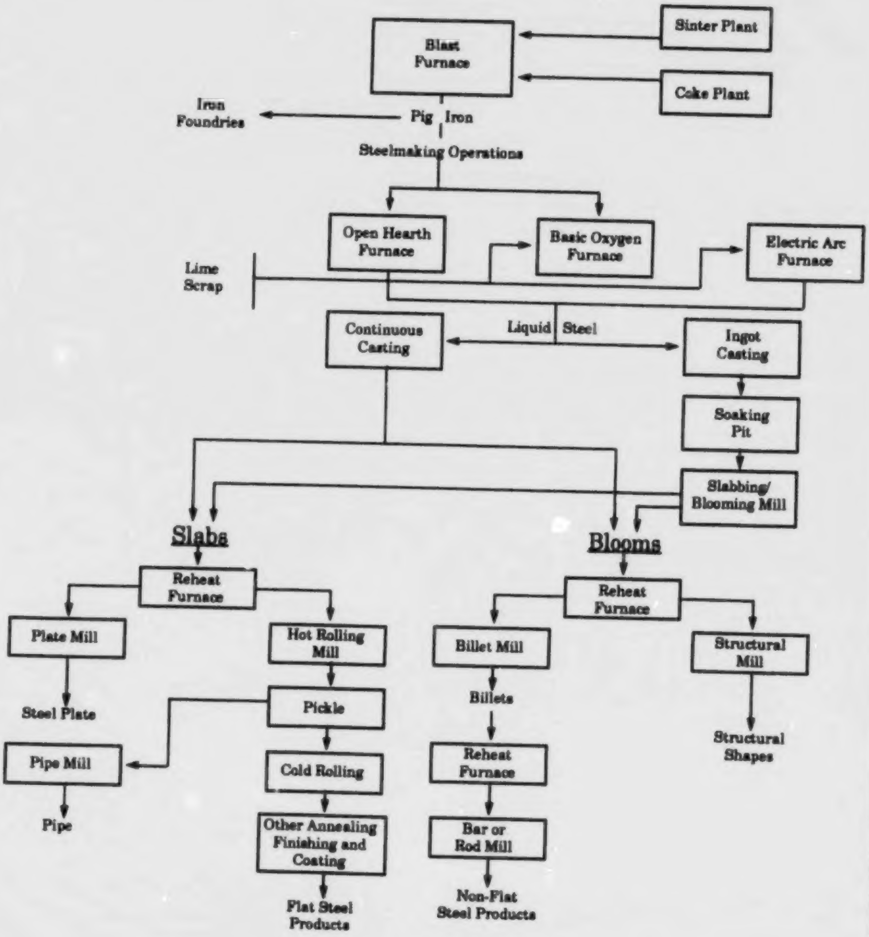
3.3.1.1 Ore Preparation

Some of the mined ore can be used without further beneficiation, requiring only washing and screening. Commonly, though, ore is reduced to pellets or sinter before entering the steel making process. To form pellets, ore is ground or crushed, mixed with additives such as binders, and dried in a pellet furnace. Sinter are porous lumps formed by mixing powdered ore, coke and additives in a semi-fluid state and drying, crushing and screening to suitably sized lumps. In an integrated steel operation, sinter facilities also fulfill the functions of a reclamation plant where small sized ore, metallic dust, sledges and scale can be recycled.

3.3.1.2 Coke Manufacture

Coke is produced by heating bituminous coal in the absence of oxygen until it becomes porous, as gas separates from the coal at high temperatures. This takes place in coke ovens which are usually part of the blast furnace plant. Unlike coal, coke will burn internally as well as on the surface, without fusing into a solid mass, and while retaining its strength under weight. The gas that is formed in this

Figure 3.2
Flowsheet of Integrated Steelmaking Operations


Sinter Plant
Blast Furnace
Coke Plant
Iron Foundries
Pig Iron
Steelmaking Operations
Open Hearth Furnace
Basic Oxygen Furnace
Electric Arc Furnace
Lime
Scrap
Continuous Casting
Liquid Steel
Ingot Casting
Soaking Pit
Slabbing/ Blooming Mill
Slabs
Blooms
Reheat Furnace
Plate Mill
Hot Rolling Mill
Steel Plate
Pickle
Pipe Mill
Cold Rolling
Pipe
Other Annealing Finishing and Coating
Flat Steel Products
Reheat Furnace
Billet Mill
Structural Mill
Billets
Structural Shapes
Reheat Furnace
Bar or Rod Mill
Non-Flat Steel Products

SOURCE: Energy and Environmental Analysis Inc., Vol. II, January 1982, p. I-3.

process is captured and passed through a recovery plant where it is stripped of by-products such as tar, pitch, ammonia and light oil. This coke oven gas is a valuable energy form with an energy content of approximately 5680 MJ/m^3. It provides fuel for the coke ovens and a surplus of energy that can be used for process heat applications in other areas of the plant. The hot coke discharged from the coke oven is sprayed with water from a quench tower to bring its temperature below the combustion point. Breeze (finely powdered coke) is another by-product produced in the final crushing and screening of coke or captured from coke oven gas.

3.3.1.3 Limestone

After crushing and screening, limestone is charged directly into the blast furnace. The use of lime in the steel making process may require a lime kiln to reduce the limestone to lime.

3.3.2 Pig Iron Production

In the blast furnace, iron ore is reduced and melted to produce molten (pig) iron and slag. The ore, coke and limestone may be supplemented by a certain amount of iron scrap. This charge is dropped into the furnace from the top of a vertical shaft. As it descends, it is met by hot, compressed air blown in through the tuyeres at the base of the stack. The hot air causes combustion of the coke, and the ore is reduced. Silica, alumina, manganese and phosphorous combine with the limestone and ash to form slag. Since slag is lighter than molten iron, it can be drained off through slag holes above the metal. Coke serves a twofold purpose in this process, providing heat through combustion and carbon for the reduction of ore to iron.

The production of hot, compressed air takes place in hot blast stoves burning blast furnace gas. The exhaust from the burners is vented through checkers of brick which absorb the heat. After an interval the burners are turned off and ambient air is blown through these checkers, recovering the heat up to 1090°C. Steam driven compressors and blowers transfer the air to the blast furnace. Steam is generated in boilers, usually fuelled by blast furnace or coke oven gas. The gas is cleaned in gas scrubbers and electrostatic precipitators before it is passed on to these process heat applications. The use of blast furnace gas in other areas of the plant is limited, as its heating value of 1080 MJ/m^3 is much lower than the heating value of natural or coke oven gas, and it generally contains a higher degree of impurities.

3.3.3 Production of Crude Steel

To produce steel from pig iron, the high carbon content of the iron must be reduced and various impurities removed. This takes place in the steel making furnace, which can be one of three types: open hearth (OH), basic oxygen furnace (BOF) or electric arc furnace (EF). Of these three, the BOF has now almost completely replaced the older, conventional OH process. EF capacity has undergone considerable growth and represents the established technology in so-called mini-mills, where steel is primarily produced from scrap. However, these EF mills cannot with present technologies produce the full range of steel products. The integrated mills using the BOF technology represent 61 percent of Canada's total steel making capacity. There is only one OH operation in Nova Scotia, representing less than 5 percent of total Canadian capacity. The remaining 34 percent is electric arc capacity from smaller plants located mainly in Quebec and Ontario.[11] This process description is therefore limited to the BOF and EF processes.

3.3.3.1 Basic Oxygen Furnace

The BOF is a pear shaped converter which can be tilted to receive the hot metal and scrap charge. It can process between 25 and 35 percent scrap in a charge. In upright position, an oxygen lance is lowered to approximately 2 metres above the charge. By blowing in high purity oxygen at supersonic speed and adding lime as a flux, the impurities are oxidized and form slag. The carbon forms carbon dioxide-carbon monoxide exhaust gas. Alloying elements such as chromium, tungsten, nickel and cobalt are added to attain a specific chemical composition.

The introduction of high purity oxygen to the steel making process has substantially reduced the process time involved. A BOF heat takes 45 minutes, whereas an OH batch without added oxygen takes 10 to 12 hours. With the addition of oxygen, the OH process time can be reduced to 6 to 7 hours. BOF capacity has increased dramatically over the years, from 30 to 35 tonnes per heat in the 1950s to 200 to 250 tonnes per heat today.[12]

A further modification of the BOF process involves injection of hydrocarbons, blown in through tuyeres in the bottom of the vessel. These hydrocarbons can come from oil, natural gas, pulverized coal or coke breeze. The purpose of hydrocarbon injection is to increase blast temperatures and thereby productivity, while decreasing coke consumption.[13]

3.3.3.2 Electric Arc Furnace

The electric arc furnace is a cylindrical shaped furnace with a relatively shallow hearth. Three carbon or graphite electrodes, projected through the roof of the furnace, provide an electrical arc. The current passes through the scrap, melting the charge. The metal is refined by oxygen blowing, removing excess carbon, silicon and other impurities and ferro-alloys are added.

The largest application of electric arc furnaces has occurred with the growth of mini-mills. Energy requirements per tonne product for a mini-mill are only one-third of the energy used in an integrated steel mill.[14] In addition the low production costs and smaller scale of operation enable mini-mills to locate close to final markets and to produce to local specifications. The electric arc process can produce a highly consistent product, providing the scrap does not contain serious impurities. Electricity has excellent control characteristics and does not add impurities to the melting process. The major disadvantages lie in the noise, safety and maintenance of the electrodes, but technological improvements will continue to alleviate these. Environmental problems also occur in disposal of the dust that collects in the fabric filters, controlling air pollution, since this dust contains both iron, zinc and traces of lead. New technologies for recovering and recycling the metallic dust are under development.[15]

3.3.4 Production of Semi-Finished Products

The molten steel must be cast into slabs, blooms or billets before it is reheated and rolled to final products. The modern method of continuous casting is now rapidly displacing conventional ingot casting.

3.3.4.1 Ingot Casting

For ingot casting, the molten steel is poured into ingot moulds, which are allowed to cool and partially solidify. While still liquid inside, the ingots are stripped from the moulds and charged into soaking pits, which are enclosed refractory chambers, to equalize their temperature and reheat for rolling. The hot ingots are sent to primary slabbing or blooming mills where these semi-finished products are rolled and cut to length.

3.3.4.2 Continuous Casting

A more advanced technology, continuous casting eliminates the casting, soaking and reheating of ingots by pouring molten steel directly into vibrating, water cooled semi-moulds. The metal is allowed to partially solidify before it is stripped from the moulds, passed over water spraying rollers to fully solidify, cut to length, inspected and transferred to storage, or to reheat and rolling of finished products. There are obviously substantial operating savings to be realized by the continuous casting process. However, the capital investment required to install the process is also substantial.

3.3.5 Reheating, Rolling and Finishing Final Products

Reheat of semi-finished steel for rolling to final products is a large process heat application. It is treated in some detail here, since it is the most important natural gas end-use market in a steel operation, and because it is undergoing rapid technological change with the potential for drastically altering the established energy use patterns. The blooms, slabs and billets are reheated to between 1065 and 1290°C either thermally or with electricity. Fossil fuel-fired reheat furnaces generally have the lowest capital costs, but new electrically-powered induction furnaces have much higher operating efficiencies. Previously, electric furnaces were limited to small batch operations for heat treating and finishing. Electric reheat furnaces represent the newest technology in this important end-use market, although improvements on thermally fired technologies are under rapid development. These will be discussed in Section 3.4.3. This section will be confined to an overview of the reheat furnace types presently in operation.

The continuous furnaces are the largest and most important reheat furnaces. Batch reheat is only efficient for smaller, non-uniform charges. The two main types of continuous fossil fuel-fired furnaces, the "pusher" and the "walking beam," will therefore be discussed and contrasted with a continuous electric induction furnace.

3.3.5.1 The Pusher Furnace

In a pusher reheat furnace, steel is moved by a mechanical or hydraulic force pushing the work pieces against each other. The longer the furnace, the more steel it will contain, and the higher the force required to move the pieces through. The capacity of such a furnace is therefore limited by the balance between the thickness of work pieces and the force required to move them. The pieces must be thick enough to prevent jamming and buckling in the furnace as they are forced through, but not too heavy for the pusher to move them.

As the steel moves along water-cooled skid pipes, it is heated from the top and bottom by two to five combustion zones with several burners firing in the opposite direction of the moving pieces. In the last zone the pieces soak in a solid hearth to eliminate skid marks and equalize the temperature of each piece.

The pusher furnace is generally a highly productive reheater both in terms of total capital and labor requirements and operating efficiency. The disadvantages are mainly a result of the pusher mechanism that limits the furnace's flexibility with respect to variations in lengths and thickness, and causes problems such as skid marks and cold stripes. The heat loss through the skid pipe system is minimized by insulation, but friction of the steel against the pipes causes wear and damage, necessitating expensive downtime for maintenance. It is common for skid pipes to be completely reinsulated every 15 to 18 months.[16]

3.3.5.2 The Walking Beam Furnace

The disadvantages of the pusher furnace led to development of walking beam furnaces. The mechanism for moving the work piece was changed to hydraulic lifters and cranks that move each piece along in given intervals, placing the pieces on the alternately positioned, stationary rails to minimize skid marks. This eliminates the need for a soaking hearth.

This furnace type exhibits much greater flexibility and higher work piece quality. The disadvantage lies in the high initial capital investment required and the high maintenance costs for the complex walking beam system. It has also exhibited lower fuel efficiencies than the pusher furnace due to heat loss to the beam system.

3.3.5.3 The Electric Induction Furnace

Although not presently in wide use for large capacity reheat due to the cost of electricity, the electric induction furnace has proven particularly attractive for the smaller mini-mills and has the potential for wider application in the industry. Steel pieces are moved by motor-driven pinch rollers at the charging end and idle rollers through the furnace. The furnace shell encloses the electric coils and a refractory lining protects the coils from higher temperatures in the furnace.

The operating efficiency advantage of an induction furnace is due to several factors. Most importantly, heating times are shorter and temperatures more uniform through a work piece, since the heat is generated inside the steel. Energy efficiency is very high under ideal conditions, but with a much wider range, from 10 to 75 percent efficiency, compared to 25 to 45 percent for fossil fuel-fired furnaces.[17] Since electric furnaces do not incur heat loss through exhaust, higher efficiency can more easily be attained. The rapid heating time also leads to a significant reduction in material losses. The problem of scaling, the formation of an iron oxide layer on the surface of the steel, is more serious in a thermally fired furnace, leading to two to three times the material losses as compared to electric induction reheat. However, electric furnaces cannot accept a wide variety of thicknesses in the work pieces without significant loss of operating efficiency, and this leads to a wider range of efficiencies depending on the product to be heated. This lack of flexibility is the major disadvantage of the electric reheat furnaces.[18]

3.3.5.4 Rolling and Finishing

From the reheat furnaces, the semi-finished forms can be rolled into final products in secondary rolling mills where they are pressed and cut into desired final shapes. These various rolling mills range from blooms going to structural and rail mills, billets going to bar, rod, pipe and tube mills, and slabs going to skelp, plate and hot strip mills. The mills are mainly driven by electricity. Major process improvements have been made in the areas of rolling speed, automation and rationalization.

The final stage of production is also a process heat end-use. Heat treatment of the finished products is necessary to control the mechanical properties of steel, primarily determined by the carbon content, the alloying elements used and the crystalline structure. Heat treatment can be of two types, either surface- or through-heating of the products. The types of heat treatment commonly performed include annealing, normalizing, sphereoidizing, hardening, tempering, carburizing and stress relieving. These processes require a heat source that will not introduce undesirable impurities and affect surface characteristics. Excess air may lead to severe oxidizing or decarburizing. Thermal fuels other than natural gas generally cause corrosion and warping of inner furnace covers. With direct gas firing at optimal air-to-fuel ratios, the combustion products form a protective atmosphere that minimizes reactions in the steel surface. This is sufficient for many applications. However, heat treatment may require specific atmospheres for special surface protection or reactions. The most common atmospheres are exothermic, endothermic and nitrogen based. Natural gas and electricity are the primary fuels used in heat treatment furnaces and for atmosphere generation.[19]

3.4 Energy Use in Iron and Steel Production

According to CIPEC's Ferrous Metals Taskforce report, total purchased energy per tonne raw steel has been almost constant at 22.9 x 10^9 joules in both 1986 and 1987. This represents a decrease in energy efficiency from 1985 of 1.1 percentage points and brings the total efficiency gain from 1974 to approximately 8 percent. The fall in energy efficiency in 1986 was caused by lower proportions of scrap, lower capacity utilization and interruptions to the operations. These efficiency fluctuations are further indications that the industry is still suffering from depressed markets and on-going structural change. The 1990 energy goal is a total efficiency improvement of 15 percent over the 1974 base year. Approximately 85 percent of Canadian raw steel capacity is covered by the CIPEC Task Force.[20]

3.4.1 Energy Flows and End-Uses of Energy

Table 3.2 shows total purchased energy use by energy carrier as reported by CIPEC.

TABLE 3.2

PURCHASED ENERGY USE BY CARRIER
IRON AND STEEL
1987

	TJ	% Share
Natural Gas	53 103	19.6
Electricity	20 554	7.6
LPP and Residual Fuel Oil	13 900	5.1
Coal	183 581	67.7

SOURCE: Canadian Industry Program for Energy Conservation, 1987 Report (Ottawa: Energy, Mines and Resources, 1988), p. 23.

These shares are quite different from those in Table 1.1 (based on Statistics Canada data), where natural gas has a 57.2 percent and electricity a 31.3 percent share of purchased energy. This is due to CIPEC's inclusion of coal as an energy form, highlighting the size and relative importance of coal in total energy use.

There are no publicly available Canadian data sources that show energy use by type of mill or by end-use category within a mill. To facilitate our discussion on specific end-uses of energy, Table 3.3 is included showing fuel use by end-use category for the U.S. steel industry. The volume shares for energy forms in the U.S. correspond very closely to those of Table 3.2, as does the total energy intensity per unit output, suggesting that such extrapolation for the purpose of qualitative discussion is not unreasonable. As a warning, though, some of the structural differences between the Canadian and American steel industries should be noted. In general, the U.S. steel industry is older, larger and has been slower in modernization of production processes. For example, 9 percent of U.S. raw steel was still produced in open hearth furnaces in 1986.[21] On the other hand, U.S. mills generally have a greater degree of fuel switchability, for example between natural gas and oil in dual-fuel fired furnaces.

The Gas Research Institute (GRI) reports that an integrated U.S. steel mill uses approximately 10 percent of its total energy in ore preparation, 40 to 50 percent in the blast furnace area, 10 to 15 percent in raw steel production and 15 to 20 percent for rolling and finishing.[22] Table 3.3 illustrates that the blast furnace area consumes almost all the coal, most of the blast furnace and coke oven gas, almost half the fuel oil, and 11 percent (45 PJ) of the natural gas used in an integrated steel mill.

Although, as pointed out in the process description, coal fulfills the dual purpose of providing carbon for the iron and heat for combustion, all coal is here classified as energy use. The amount of coal needed to produce a tonne of coke has been stable over time but the coking rate, the amount of coke used per tonne of pig iron produced, has shown a downward trend. This is due to process and material changes, such as increased furnace capacities, higher temperatures, injection of other hydrocarbons and higher quality raw materials, which reduce the need for coke in pig iron production. Although both the coking process and pig iron production are highly efficient operations, Table 3.3 shows that it is essential for energy efficiency that full use is made of the waste gases produced, as the total heating values of blast furnace and coke oven gas exceed the heat content of the natural gas volumes used.

In the steel making sector, developments have also been towards greater capacities, decreased process time and higher quality products. Some changes, such as injection of hydrocarbons and high purity oxygen, are of limited consequence for energy use patterns. The

TABLE 3.3

U.S. IRON AND STEEL MILLS
1984
(percentage share of each fuel applied across end-use categories)

	Blast Furnace	Other Blast Furnace Area	Steel Melting	Heating and Annealing	Other	Total	
						(%)	(PJ)
Natural Gas	8	3	5	58	26	100	412.57
Coke Oven Gas	4	42	--	27	27	100	204.44
Blast Furnace Gas	37	28	--	2	33	100	238.87
Fuel Oil	41	2	17	18	23	100	50.83
Tar and Pitch	31	--	54	18	23	100	4.11
LPG	--	--	--	--	100	100	0.10
Coal	94	--	--	--	6	100	1078.00
Coke[a]	100	--	--	--	--	100	75.4
Electricity	N/A	N/A	N/A	N/A	N/A	--	177.50

1984 Total Energy Use: 1794.43 PJ[b]
1984 Total Production: 66.53 million tonnes final products.

SOURCE: Hagler, Bailly and Company, Competitive Position of Natural Gas in Steel Reheat Applications, report prepared for the U.S. Gas Research Institute (Chicago: GRI, August 1986), p. 75.

[a] Coke represents purchased coke not converted from coal in the plant.

[b] Total energy use does not include coke oven gas, blast furnace gas or tar and pitch because these are by-products derived from coal and their energy value is included in the coal figure.

increase in scrap recycling with the electric arc process represents a more fundamental change in steel operations. Electric melting of scrap reduces total energy consumption per tonne by almost two-thirds, since the most energy-intensive stage of the process becomes redundant. Electricity consumption per tonne increases by a factor of approximately 2.7 and natural gas consumption has also shown a slight increase when measured per tonne output with the electric arc process.[23] The reason natural gas does not suffer any loss of end-use markets with electric steel making is that the largest natural gas applications of reheat, heat treating and finishing are maintained, and that without other waste gases available, natural gas expands its potential in process heat applications. Table 3.3 clearly shows the importance of the reheat and heat treating applications for natural gas use.

Natural gas has had a competitive advantage over oil in reheat applications due to its clean burning characteristics. Oil flames are luminous, which provide better heat transfer within a furnace, but flame impingement causes local melting and scale buildup on the product. Trace elements from combustion also lead to product contamination, corrosion of recuperators and deterioration of refractory linings. By firing with excess air these problems are minimized; however, this also significantly lowers the efficiency of the furnace.

Natural gas is now facing increasing competition from electricity in the reheat market, as new technologies are implemented changing both the amount and the nature of reheat required. The elimination of soaking pits, as the industry moves from ingot to continuous casting, represents a decrease in total reheat requirements and provides a surplus of coke oven gas. However, some additional process heat needs are created as the tundish must be heated to prevent heat loss and metal freezing in the nozzle. The practice of hot charging semi-finished steel directly from the moulds into reheat furnaces represents a large energy conservation potential, as total reheat requirements can decrease by as much as 50 percent.[24] The end-use overview shows that natural gas would feel the largest impact of such a reduced reheat market.

In heat treating, the predominant energy source is also natural gas. According to GRI sponsored research into U.S. production processes, natural gas has a market share of 93 percent in primary steel metal heat treating and atmosphere generation, compared with electricity's 3 percent.[25] Cost and performance comparisons between equipment types are difficult to carry out, as the capital is very application specific. The general conclusion of GRI's study, however, is that gas fired equipment is cheaper but less efficient than electric equipment, and that electricity-based technologies such as vacuum and plasma furnaces will penetrate mostly as capacity additions for advanced materials and alloys production.

The gas industry is currently developing and testing a host of technologies aimed at the heat treating market, such as high-temperature fluidized beds, improved flame hardening equipment, and designs and equipment that will ease the automation, process control and integration of heat treatment with the rest of the production process. An example of such integration is the development of a new atmosphere generator placed inside the heat treating furnace, decreasing total energy requirements and eliminating the need for separate atmosphere equipment.[26]

3.4.2 Changes in Energy Efficiency

The theoretical minimum energy requirement for raw steel production has been estimated at 8.74×10^9 J/tonne.[27] This corresponds to a more than 60 percent reduction in energy use from the level of 22.9×10^9 J/tonne found in Canada in 1987.[28] Although a theoretical minimum is by definition unattainable, it indicates that substantial conservation gains can still be made in this industry.

Increasing continuity of processes can be facilitated by advanced automation and control systems. Such systems permit complex scheduling, coordination and control of operations, and reduce the need for cool-down and inspection of both products and equipment. It is an area that will likely contribute considerably towards increased operating efficiency in general, and fuel savings in particular, while also increasing electricity consumption at the expense of other energy inputs.

Since steel making is dominated by process heat end-use applications, waste heat recovery becomes the focus of energy efficiency efforts. Such recovery requires unique systems and solutions for each plant, varying with plant logistics and specific energy needs. Solutions may range from simple retrofits to major capital replacements.

Energy carried off by hot flue gases represents the largest source of heat loss from furnaces, lowering the efficiency of thermal combustion. Recuperators are therefore becoming standard equipment on thermally fired furnaces. Recuperators capture the heat and use it to preheat combustion air going into the furnace. Although an established technology, recuperators are under continual improvement to correct problems such as cracking or buckling, corrosion and fouling. Both improved engineering designs and improved materials will continue to make recuperators an attractive investment and contribute to increasing energy efficiency. However, the implementation of high performance recuperators will be slowed by the high cost associated with breakdown and maintenance. Any process interruption causes severe scheduling problems that affect the entire integrated production process. Operators will therefore prioritize high reliability over high performance and risk of breakdown.

Using the waste heat to operate boilers is another option in heat recovery. Waste heat boilers can be very efficient since, in general, heat transfers more efficiently from gas to liquid than from gas to gas. The problems with retrofitting boilers lie in matching their steam supply to plant requirements, and in the capital investment required.

Burners are also undergoing developments to improve design and efficiency. Parallel to developments in recuperators, burners must be developed which are designed to handle preheated combustion air. Flame direction, heat release patterns and temperature uniformity are important design characteristics. For total efficiency, it is vital that a burner maintains high efficiency when turned down. High velocity burners represent a promising technology development, as do flat flame and recuperative burners.

A new generation of regenerative burners have been developed in which two identical burners fire alternately, switching between functioning as burners and furnace flue. When switched off, the burner can store flue heat which preheats combustion air when it is turned on again. The technology is old, and the movement has long been towards recuperators rather than regenerators, but modern advances such as compact materials and faster valve cycling have hastened the re-emergence of regenerators as an interesting energy efficiency investment.[29]

Significant progress has also been made in indirect fired reheat furnaces, overcoming problems of rapid deterioration of gas-fired tubes at high temperatures by using ceramic materials. The resulting low maintenance, highly adaptable units provide a controlled atmosphere with rapid heat up and low energy costs.[30] Such developments will improve energy efficiency and enhance the competitive position of natural gas.

Heat loss through water cooling of furnace skids represents another important area for conservation. Improved insulation materials, tile shapes and attachment methods will encourage energy efficiency in this area. Any improvements that reduce downtime for maintenance will be especially easy to implement. Alternative cooling technologies may also aid conservation efforts. Evaporative cooling, where the skid pipes act as boiler tubes in converting water into low grade steam, has been demonstrated. Problems with reliability and maintenance requirements need to be satisfactorily addressed for this to become a commercially viable option.

Finally, conservation through improved refractory linings and insulation will contribute to energy efficiency. Plastic and ceramic fibre materials can improve furnace efficiency while reducing maintenance. In conclusion, there appears to be a large potential for conservation efforts, particularly in the area of heat recovery. However, such investments will be considered in the context of all operation changes, with a primary view to product quality improvement and cost control.

3.4.3 Technological Change

The preceding sections have discussed the trend in steel making towards increasing continuity, coordination and integration of operations. Two such developments have been discussed, hot charging and continuous casting. An extension of this is direct rolling of hot semi-products into final products.

3.4.3.1 Direct Rolling

With direct rolling, the reheat process is limited to equalizing temperatures by heating corners and edges. It may also be necessary to melt a thin surface layer to remove defects such as oxidized steel or cracks.

The virtual elimination of reheat clearly promises substantial efficiency savings. The main problem with adoption is that direct rolling does not represent an easy retrofit option. It may involve changing the entire plant layout, requiring major capital investment. It also requires very careful scheduling of equipment and a back-up system for ambient temperature treatment and storage in case of equipment failure or maintenance. Complete implementation of the technology is, therefore, likely to be held back by the scheduling problems and capital costs involved. However, one Canadian producer is already direct rolling steel.

The challenge for natural gas will be to remain competitive in reheat applications, as the market is reduced and the nature of reheat requirements is altered. The fully integrated processes will require quick and selective reheat in a continuous mode. This favours present electro-technologies which have the added advantage of being easily connected with automated and computer controlled systems.

3.4.3.2 Thin Steel Casting

By casting low carbon, liquid steel directly into thin slab, sheet or strip products, reheat is limited to surface and edges. In addition, the amount of rolling required is much lower. This becomes the next step in the integration of processes, going directly from liquid steel to a nearly finished product. Demonstration projects with federal funding are well underway in the U.S., but several problems must be solved before the technology can become widely commercially viable. The principal problem concerns the quality of the steel produced. Surface defects and cracking commonly occur and the grain structure of thin cast steel must be better understood. Additional heat treating to alter the microstructure of thin cast steel may be required.

It is expected that thin slab casting will be developed before thin strip casting. It is unlikely, given the technical problems involved, that thin steel technology will gain widespread acceptance in the next 10 years. In the case of thin strip casting it may take as long as 20 years to significantly penetrate the industry.[31] Thin steel casting technology results in substantial energy savings, as both reheat furnaces and rolling mills become redundant, while some additional process heat may be required in the heat treating section. In heat treating, the technological advances have also been towards continuous, energy-efficient production as in jet heat recuperating, continuous strip annealing furnaces.[32] Thin steel casting may be the technological development required for mini-mills to move into flat products, the bulk product market which has been reserved for integrated producers. Given commercial demonstration, penetration of this technology will likely be faster if adapted for mini-mill production.

3.4.3.3 Direct Reduction

The movement towards a more efficient blast furnace process, starting with hydrocarbon injection and oxygenation, has led to development of a number of direct reduction processes. One of the main advantages of such processes is that they allow for the use of non-coking coals or other hydrocarbons for reduction and combustion. This does away with coke preparation and handling, significantly reducing the size of the iron producing facilities. The much lower minimum capacity of direct reduction furnaces adds to the flexibility of the process. It is in particular an advantage for adaptation to mini-mills. Provided that full use can be made of the waste gas produced, the process can be highly efficient and cost-effective.

The Midrex process, manufacturing pre-reduced, porous pellets, is an example of the first step in direct reduction. These pellets still contain at least 5 percent rock and other particles, and tend to be very reactive, which makes them difficult to store and ship. In a direct reduction furnace, 100 percent molten iron can be obtained without the use of coke.

The difficulty in transporting and storing the highly reactive, directly reduced pellets is solved by compressing the pellets into briquets. This hot briqueted iron (HBI) is not reactive, allowing production to take place in areas with the advantage of cheaply available energy, particularly natural gas, and the HBI to be transported to steel producers closer to final markets. Venezuela is the largest producer of direct reduced iron in the world. HBI can be produced in Venezuela at one-third of the cost of comparable production in the U.S.[33]

3.4.3.4 Direct Smelting

A third generation of iron making processes, direct smelting, is now under development. Direct smelting technologies allow for production of molten iron without the use of metallurgical coal while dispensing with the pelletizing process. The ore is usually first partially reduced in a shaft-type furnace and the process is completed in a molten bath.

The lower temperatures involved in direct smelting result in fewer undesirable elements, such as sulphur, in the iron. Fewer emissions also provide a more environmentally acceptable production process. In addition, just as for direct reduction, down-sizing of facilities leads to reduced capital costs and increased flexibility of operations. Most of the direct smelting technologies are based on the use of low grade, non-metallurgical coal.[34]

The commercial viability of direct reduced iron and direct smelting depends crucially on the price and availability of scrap. Since mini-mills do not have ore smelting facilities, higher price or short supply of scrap will make directly reduced iron an attractive alternative. As scrap-based production increases and continuous casting limits the availability of scrap, direct reduction facilities will become more attractive investment options for steel producers.

3.4.3.5 Cogeneration

The potential for cogeneration in the iron and steel industry is highly dependent on individual plant layout and steam balances. The Ontario Ministry of Energy recently commissioned a cogeneration study, which identified a financially implementable potential of 105.6 MW in the Ontario iron and steel industry. This is lower than for any of the other primary, energy intensive manufacturing industries, representing only 7 percent of the total industrial cogeneration potential likely to be implemented in Ontario by 2000.[35]

3.5 Conclusions

The most significant change in this industry has been the growth in steel production from scrap. With the phasing out of open hearth furnaces, and the basic oxygen furnace's limited scrap handling capacity, the electric arc furnace has penetrated the market, through its ability to handle 100 percent scrap. This growth in electric raw-steel making has not displaced natural gas. In fact, recent development efforts have shown that combining electric and natural gas melting may be the most efficient process. Whereas gas technologies are most efficient for raising temperatures up to approximately 800°C, electricity is the most efficient energy form for higher temperature variations.[36] Using hybrid combinations, whereby the scrap is preheated by efficient oxygen-natural gas burners in the initial phase and further melted by electricity, represents such an optimal combination. Since electric melting is limited to radiation from the arc, natural gas burners increase the heat transfer by introducing convective heat.[37] Further, natural gas may be needed for thermal treatment of bag house dust, reducing lead and zinc to slag and oxides. A further problem with electric arc furnaces, electric transients, may be solved with a gas-fired generator built to withstand such fluctuation. An all-gas scrap melter has also been developed using submerged combustion of natural gas. It is currently at the demonstration stage.[38] These are indicative of the host of gas technologies forthcoming in response to industry needs.

The most important end-use market for natural gas is in the last stages of production, primarily in reheat of steel for rolling. The traditional reheat market is on the threshold of major changes. With new production technologies that virtually eliminate the need for reheat, the nature of the remaining reheat requirements is also changing. The emphasis is now on developing reheat technologies that provide fast and selective continuous heating, rather than batch reheat from ambient temperatures. Electricity, particularly electric induction, has the advantage of a high degree of controllability and of being easily integrated into automated production facilities. The disadvantages lie in high capital and maintenance costs, the high cost of electricity over thermal fuels, and in the systems' sharp efficiency decline when handling off-design stock.

Gas technologies are now being developed that compete with electric induction. Gas-fired rapid heating, or quick reheat, is accomplished in a direct-fired furnace modified to increase both convective and radiation heating, using high velocity burners. Limitations of such quick reheat furnaces arise from the fact that all thermal sources convey heat from the outside, so that internal temperatures are restricted by the conductivity and the thickness of the steel. However, the resulting limitations in handling off-design stock are not as severe as for electric induction furnaces. At substantially reduced capital and maintenance cost, compared to induction, the rapid heating furnaces solve the problem of high scale loss and avoid the associated costs of stock treatment which are incurred under the conventional thermal processes.

Implicit in the integration of processes and the aim to restrict reheat is a need for maintaining and equalizing heat and supplementing for heat loss at various stages of production. Again, natural gas and electricity are competing. For example, alternative new technologies and materials for ladle and tundish heating and improved high temperature sensors and controls are under continued development for both energy forms.

As process technologies such as thin steel casting are developed, scrap based mills will be able to compete in the whole range of steel product markets. In this competitive steel market, producers will continuously seek to rationalize the production processes. The competition between electric and natural gas technologies can be expected to continue and intensify in this environment.

Footnotes

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[8] See Figure 1.6, Chapter 1.

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[18] Ibid.

[19] J. E. Tracey, Heat Treating and Furnace Atmospheres, Heat Treating Processes, Consumers Gas Company (Toronto: Canadian Gas Association, 1988).

[20] Canadian Industry Program for Energy Conservation, Taskforce Reports 1986 (Ottawa: Department of Energy, Mines and Resources, 1987).

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[22] Ibid., p. 22.

[23] Ibid., p. 24.

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[25] Hagler, Bailly and Company. Competitive Position of Natural Gas: Ferrous Metal Heat Treating and Atmosphere Generation Applications, report prepared for the U.S. Gas Research Institute (Chicago: GRI, October 1987).

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[31] Ibid.

[32] Energy and Environmental Analysis Inc., 1982 p. I-54.

[33] Iron and Steel Society, W. O. Philbrook Memorial Symposium, Abstracts, 7th Process Technology Division Conference, 47th Iron Making Conference, 71st Steelmaking Conference, April 17-20, 1988 Toronto (Warrendale, P.A.: Iron and Steel Society Inc., 1988), pp. 166 and 167.

[34] Ibid., pp. 39-40, 42 and 49.

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[36] Hagler, Bailley and Company, 1986, p. 99.

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Chapter 4

PETROLEUM REFINING

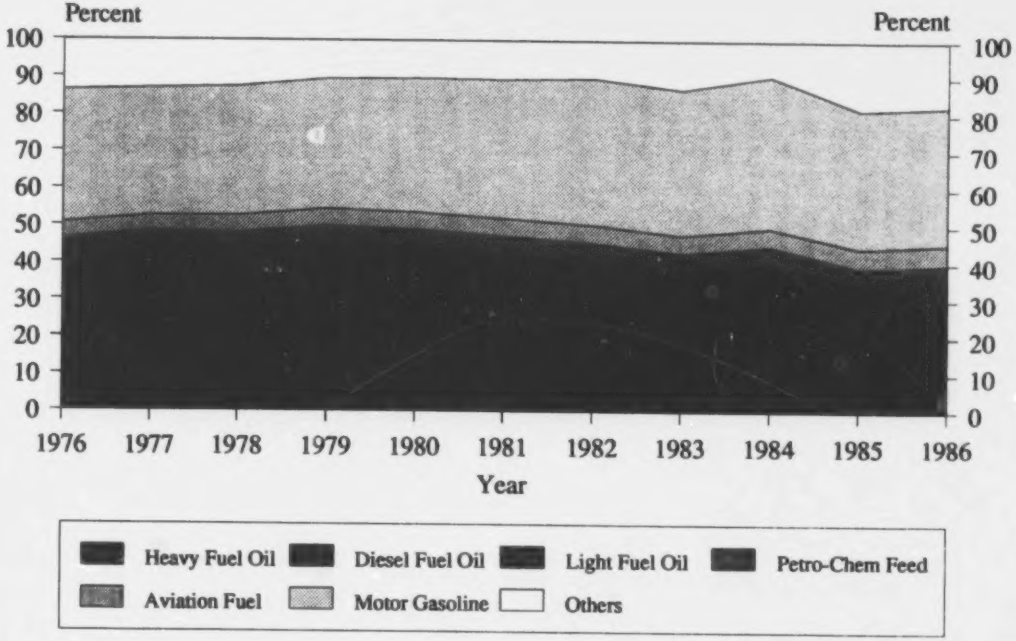
The refined petroleum products sector, SIC code 361, is the largest 3-digit sub-segment of the refined petroleum and coal products industries. The industry produces a variety of fuels: motor gasoline, kerosene and distillate fuel oils, as well as a wide spectrum of products for such non-fuel uses as chemical feedstocks, lubricants and road surfaces. Motor gasoline is the principal product of the industry, representing more than 37 percent of physical production. As shown in Figure 4.1, diesel fuel oil represented 16.6 percent of total refinery production, and light fuel oil 9.5 percent in 1986.[1] Physical output exceeded 895 million cubic metres in 1986.[2] The total value of shipments for the refined petroleum and coal products industries in 1986 was $19.5 billion.[3]

4.1 Size and Significance of Canada's Refining Industry

The size of the Canadian industry is considerable, when viewed in the context of both the number of plants and the crude oil capacities of operating refineries worldwide. In 1986, Canada's 29 refineries ranked third in number of operations behind only those of the United States (189) and Japan (44).[4] With regard to crude oil capacity, Canada's 1.9 million barrels per day was seventh behind that of the U.S., U.S.S.R., Japan, Italy, Germany and France.[5] Yet, despite the international magnitude of the industry, its domestic importance is even greater. While Canada is a net exporter of refined petroleum products, the volume of transfers of refined petroleum products across Canada in 1986 was more than twice the volume of exports.[6]

This decade the evolution of the refining industry in Canada has produced some notable changes. From 1980 to 1986, the number of operating refineries was reduced from 38 to 29, yielding a 15 percent decline in total refinery capacity. This drop in capacity is more significant when considered on a regional level. Table 4.1 illustrates the regional changes in refining capacity from 1980 to 1986, reflected both in terms of absolute volume changes and percentage changes, and shows that there has been a clear transfer of capacity from the East to the West.

Figure 4.1
Yields of Refined Petroleum Products



Source: Canadian Petroleum Association,
Section VIII, Table 7, 1987.

TABLE 4.1

REFINERY CRUDE OIL CAPACITY BY REGION
1980-1986

	Change in m^3/cd[a]	Change in Percent	1986 Total Capacity in m^3/cd[a]
Atlantic	(2 120)	(4)	56 010
Quebec	(49 195)	(50)	49 350
Ontario	(21 632)	(21)	79 434
Manitoba	(4 770)	(100)	–
Saskatchewan	780	10	8 610
Alberta	21 284	30	91 855
B.C.	770	3	26 950
N.W.T.	40	9	500

SOURCE: Canadian Petroleum Association, Statistical Handbook (Calgary: Canadian Petroleum Association, April 1987), Section VIII, Table 3B, 1987.

[a] Cubic metres per calendar day.

The Canadian petroleum refining sector has not rebounded well following the 1982-83 recession. The refinery utilization rate in Canada fell to 72 percent in 1982, and has since remained relatively stable, increasing moderately to 77.2 percent in 1986.[7]

4.2 Regional Supply of Refined Products

The principal determinants of the supply of refined products are the refinery feedstock, the degree of complexity of the refinery processes, associated transportation and storage costs, and the nature of the supply arrangements between refiners.

4.2.1 Refinery Feedstock and Complexity

The basic raw material for refineries is crude oil, even though synthetic crude oil from tar sands and condensate from natural gas are incorporated in some refinery feedstocks. Crude oil is a complex mixture of chemical compounds, predominantly hydrocarbons, which also contain impurities such as sulphur, nitrogen and metallic compounds. Given the wide quality differences between crude oils produced in the world today, various properties of available crude oils are important factors in the purchasing decisions of refiners. Among these considerations, chemical and physical properties such as density and sulphur content are the most important in evaluating the quality of crude oil.

Refineries vary considerably by degree of process complexity, from fully integrated, highly complex plants to very simple plants. Table 4.2 illustrates the regional diversity of processes used in the existing operating refineries across Canada. The numbers reflect the charge capacity for selected processes of Canadian refineries as of January 1, 1986. The data are expressed both in terms of percent of total crude entering refineries, and in cubic metres which can be processed per calendar day.

The figures show that wide differences do exist in certain refining processes from province to province. For example, vacuum distillation separates 47 percent of the crude in Nova Scotia compared to only 19 percent in Alberta, and catalytic hydrotreating is used for 66 percent of the crude in Alberta, as opposed to only 27 percent in Saskatchewan. Most noteworthy is the disparity in the use of thermal operations, from 40 percent in Alberta to not at all in the Northwest Territories, British Columbia and Nova Scotia, and only 5 and 6 percent, respectively, in Ontario and Quebec. Bunker fuel, a grade of residual fuel oil used to power ships, is largely the reason for this difference. Whereas the Northwest Territories, British Columbia, Nova Scotia, Ontario and Quebec are all situated near major waterways, Alberta's geographic location results in no market for bunker fuel. In Alberta, therefore, coking processes are more commonly incorporated to convert this heavy residual petroleum fraction into lighter products, accounting for the large share of thermal processes in Alberta. Alternatively, refineries without coking facilities can produce large quantities of asphalt.

The petroleum refining industry can be classified as a very large energy user, with an important qualification regarding differentiation between purchased and self-produced energy. The amount of energy consumed in the refining process will increase directly with the complexity of the refinery. However, as more complex processing units are integrated, the interdependence between each process also increases directly. Consequently, a large amount of the energy required for the production of refined petroleum products is self-produced. More detail concerning the energy flows and requirements for refinery processes is provided in Section 4.4.

4.2.2 Supply Arrangements and Transportation

The operation of a refinery depends on the continuous flow of crude oil feedstock, and semi-processed and refined products through the plant. Interruptions in the flow process, from either

TABLE 4.2

CHARGE CAPACITIES FOR SELECTED REFINING PROCESSES OF CANADIAN OPERATING REFINERIES, JAN. 1, 1986

(in percent of total crude entering refineries,[a] and in cubic metres which can be processed per calendar day)

	North West Territories	British Columbia	Alberta[b]	Saskatchewan	Ontario	Quebec	New Brunswick	Nova Scotia	Total
No. Plants	1	6	8	2	6	3	1	2	29
Crude	500	26 950	91 855	8 610	79 434	49 350	39 730	16 280	312 790
Vacuum Distillation	--	8 610 (32)	17 015 (19)	3 300 (38)	27 950 (35)	19 710 (40)	10 334 (26)	7 667 (47)	94 586 (30)
Thermal Operations	--	--	37 130 (40)	1 000 (12)	4 070 (5)	2 795 (6)	3 180 (8)	--	48 175 (15)
Catalytic Cracking	--	8 398 (31)	14 630 (16)	2 150 (25)	19 300 (24)	11 460 (23)	3 021 (8)	4 745 (29)	63 704 (20)
Catalytic Reforming	--	5 220 (19)	10 150 (11)	1 403 (16)	20 586 (26)	10 830 (22)	6 120 (15)	1 972 (12)	56 281 (18)
Cat. Hydro-Treating	--	13 750 (51)	60 633 (66)	2 290 (27)	30 316 (38)	20 500 (42)	15 810 (40)	8 299 (51)	151 596 (49)

SOURCE: Canadian Petroleum Association, Statistical Handbook (Calgary: Canadian Petroleum Association, April 1987), Section VIII, Table 4, 4A, 1986.

[a] Percentage figures are shown in parentheses. Due to the integrated sequential nature of refining processes, double counting occurs, and percentage figures will not add to 100.

[b] Includes synthetic crude facilities in Alberta.

disruptions in feedstock supply or a failure to ship refined products, can involve considerable operations costs. Therefore, sufficient transportation and storage capacity are required to maintain a continuous flow process. Accordingly, the cost of transporting crude oil and refined products presents refiners with significant financial and logistical hurdles.

The issue of transportation costs is complicated further by Canada's vast geographical area and its relatively small population. Given these limitations, refiners do not have the option of operating a refinery in each region of the country. Consequently, in order to both lower their transportation costs and increase their flexibility in providing a continuous supply of refined product to integrated marketing facilities, refiners enter into a variety of supply and distribution arrangements with each other. The nature of these supply arrangements between refiners consists of the exchange, purchase and storage of each other's products, as well as the occasional processing of another refinery's crude oil.[8]

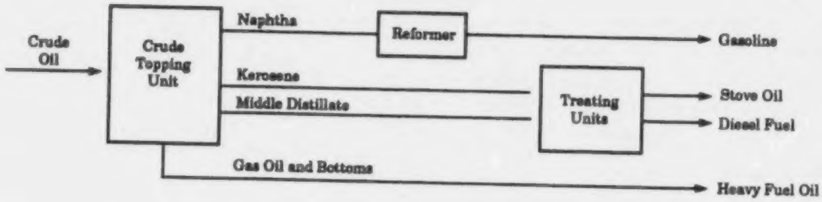
4.3 The Production Process

In terms of the degree of complexity of manufacturing processes, refinery operations are considered to be some of the most technically sophisticated. The variations that exist in the processing units and the degree of process integration serve to differentiate petroleum refining from other manufacturing industries. Such differentiation continues within the industry itself as the crude slates, product lines, and process configurations are unique for each individual refinery. The problem with such variation is that it becomes difficult to describe a "typical" refinery.

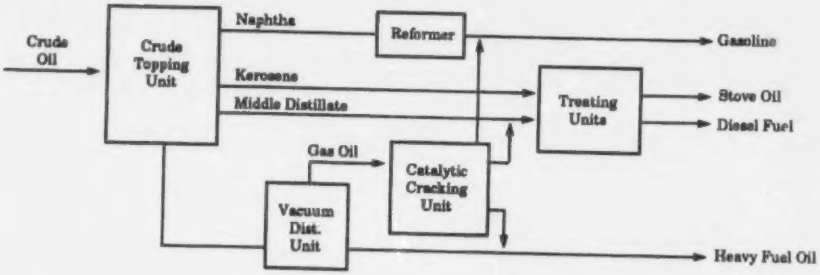
In Canada, refineries are usually classified into three categories: skimming or topping refineries integrated refineries and complex refineries. At present, the skimming classification is virtually obsolete as most of these refineries have either been upgraded or replaced due to a change in demand patterns favouring lighter products. Figure 4.2 provides a simplified process flow diagram for each refinery classification.

Figure 4.2
Schematic Flowsheets of Refineries

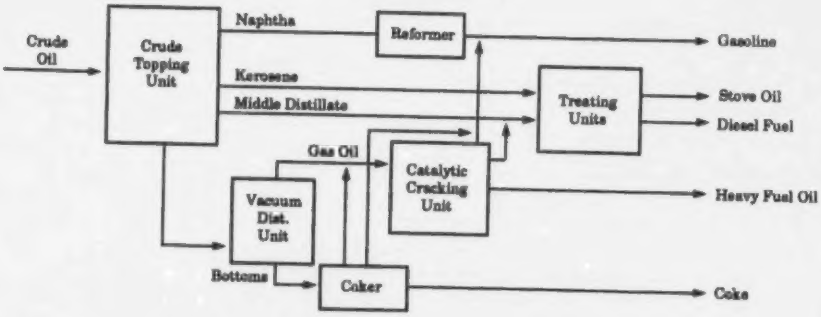
A Skimming Refinery


Crude Oil
Crude Topping Unit
Naphtha
Reformer
Gasoline
Kerosene
Middle Distillate
Treating Units
Stove Oil
Diesel Fuel
Gas Oil and Bottoms
Heavy Fuel Oil

An Integrated Refinery


Crude Oil
Crude Topping Unit
Naphtha
Reformer
Gasoline
Kerosene
Middle Distillate
Treating Units
Stove Oil
Diesel Fuel
Gas Oil
Catalytic Cracking Unit
Vacuum Dist. Unit
Heavy Fuel Oil

A Complex Refinery


Crude Oil
Crude Topping Unit
Naphtha
Reformer
Gasoline
Kerosene
Middle Distillate
Treating Units
Stove Oil
Diesel Fuel
Gas Oil
Catalytic Cracking Unit
Heavy Fuel Oil
Vacuum Dist. Unit
Bottoms
Coker
Coke

SOURCE: Alberta Petroleum Marketing Commission.

Using a large scale complex refinery as a reference, a typical refinery would include most of the following processing units divided into three process stages: separation, conversion and upgrading:

Separation:

- Atmospheric distillation
- Vacuum distillation

Conversion:

- Thermal cracking
- Catalytic cracking
- Hydrocracking
- Catalytic reforming
- Alkylation
- Aromatic/Isomerization

Upgrading:

- Hydrotreating

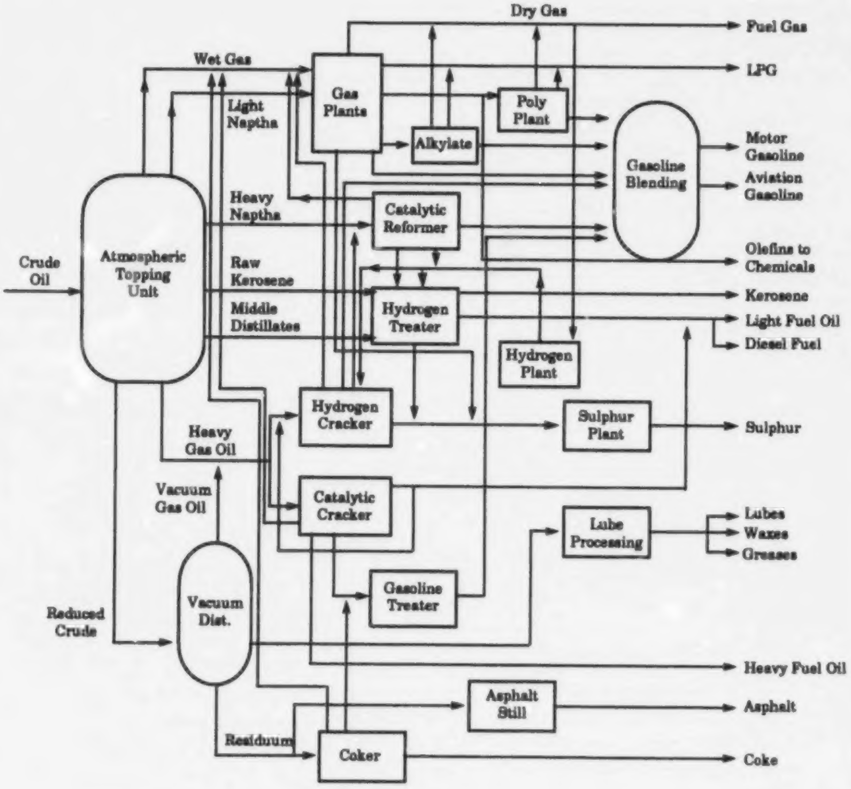
Figure 4.3 presents a detailed process flow diagram for a typical complex refinery.

4.3.1 Separation Process

The distillation of the crude feedstock is the first major operation in the petroleum refining process. The crude oil is heated and charged to distillation units, or crude stills, which separate the crude oil into fractions (cuts) according to boiling point ranges (cut points). Distinct products are then obtained by condensing the vapours produced at the different cut points.

To achieve greater efficiencies and lower costs, the separation of the crude feedstock is carried out in two steps.[9] First, the total crude oil is fractionated at near-atmospheric pressure. This operation, referred to as either atmospheric, topping, or crude distillation, separates out the low-boiling top fractions (straight-run products). The second step of the separation process is to then feed the high-boiling bottoms fraction (residue or topped crude) to a vacuum distillation unit. As boiling points are lowered when the pressure is reduced, the result is an increase in the yield of top-end fractions. For plants processing synthetic crude oil, this vacuum distillation unit is not required.

Figure 4.3
Process Flow Diagram for a Typical Complex Refinery


Dry Gas
Fuel Gas
Wet Gas
LPG
Gas Plants
Light Naptha
Poly Plant
Alkylate
Motor Gasoline
Gasoline Blending
Aviation Gasoline
Heavy Naptha
Catalytic Reformer
Crude Oil
Atmospheric Topping Unit
Raw Kerosene
Olefins to Chemicals
Kerosene
Middle Distillates
Hydrogen Treater
Light Fuel Oil
Diesel Fuel
Hydrogen Plant
Hydrogen Cracker
Sulphur Plant
Sulphur
Heavy Gas Oil
Vacuum Gas Oil
Catalytic Cracker
Lube Processing
Lubes
Waxes
Greases
Gasoline Treater
Reduced Crude
Vacuum Dist.
Heavy Fuel Oil
Asphalt Still
Asphalt
Residuum
Coker
Coke

SOURCE: Marshall Sillig, Petroleum Refining Industry, Energy Saving and Environmental Control, 1978.

The straight-run products that result from distillation are used as feedstocks for subsequent processing units or are blended into final products. Naphtha, the lightest fraction taken from the top of the distillation unit, usually goes directly into gasoline. Heavy naphtha, however, requires further processing by catalytic reforming to improve its octane number. Kerosene and the middle distillates (light fuel oils and diesel fuel) are usually charged to hydrotreaters or desulphuring units. Gas oil, the straight-run product of the topping process with the highest boiling point, constitutes the feedstock for catalytic cracking, or hydrocracking.[10]

4.3.2 Conversion Process

The conversion processes are actually what delineate the various refinery classifications. While skimming refineries possess no such facilities, integrated and complex refineries are differentiated by the scale of their conversion operations. Specifically, referring back to Figure 4.2, one will note the addition of a coking facility in the process flow of the complex refinery. This augmentation in the conversion process provides a complex refinery with added flexibility, enabling it to further increase its yield of refined product.

The purpose of conversion processes is to convert the heavier oils to lighter, higher-value products, particularly gasoline and middle distillates, thus obtaining a greater end-yield from a given barrel of crude oil.[11] The processes involve chemical reactions under high temperatures and pressures in order to change the molecular weight and structure of the feedstock. In many cases, these chemical transformations are achieved with the aid of a catalyst.

4.3.2.1 Thermal Cracking

Thermal cracking is a process which subjects the heavy residual feed from the distillation units to temperatures sufficiently high to fracture the hydrocarbon molecules into smaller units.[12] Coking and visbreaking (viscosity breaking) represent the two major thermal cracking processes. Visbreaking is a mild thermal cracking process which reduces the viscosity of the vacuum residue such that it conforms to marketable fuel specifications. In contrast, coking is thermal cracking under severe temperature and pressure conditions that converts the vacuum residuum completely into gas, gasoline, coke and gas oils. While a considerable amount of crude oil is charged to cokers in Alberta for the processing of heavy petroleum and synthetic crude (see Table 4.2), the overall application of thermal processes in Canadian refineries today is limited.

4.3.2.2 Catalytic Cracking

Catalytic cracking (or cat cracking) remains the single most important and widely used conversion process.[13] Cat cracking represents an improvement on the basic thermal processes, as it results in higher gasoline yields, more of the higher octane hydrocarbons, and less residual oil.

The facilities used in cat cracking are classified as either moving-bed or fluidized-bed units, with the latter unit being used more extensively. In the fluidized-bed process, straight-run heavy gas oils and vacuum gas oil are heated under pressure in the presence of a catalyst to promote cracking. The catalyst is in the form of very small particles which behave as a fluid when suspended in upflowing gas. The catalyst enables the operation to be conducted at lower temperatures and pressures than thermal cracking, thus permitting both a higher conversion of feed and a higher gasoline yield. However, the coke produced in the catalytic process remains on the catalyst and lowers its activity. To correct this, the catalyst is regenerated by burning the coke off with air.

The products of the cat cracking process include gases (C_4 and lighter), gasoline, light cycle oil, heavy oil and coke. Cat cracked gasoline, the main product, has high octane numbers and makes a good motor gasoline blending component. The light cycle oil can be either hydrocracked or hydrotreated for subsequent use as a light fuel oil component. The heavy cycle oil can be used as a residual fuel component, while the coke produced is burned off in the unit, providing a large amount of process heat for internal use.

4.3.2.3 Hydrocracking

The hydrocracking process is merely cat cracking at very high pressures in the presence of hydrogen. Hydrocracking is not a substitute for cat cracking, rather it supplements the cat cracking process by handling the light cycle oils and thermal cracker distillates which resist catalytic cracking. If a refinery has both processes, the cat cracker takes the more easily cracked atmospheric and vacuum gas oils, although these gas oils constitute possible feedstocks to a hydrocracker as well.

The benefit of incorporating a hydrocracker into the refinery process lies in the versatility of the hydrocracking unit itself. In addition to providing a better balance of gasoline and distillate production, hydrocracking results in: higher gasoline yields, improved octane quality of both pools of blending stock (gasoline and distillates), and the production of relatively large amounts of isobutane which are used to balance the feed to the alkylation process.[14]

Hydrocracking is still a relatively new process, but one that is of increasing importance in view of the trends to heavier crudes and the need for processing synthetic crudes.[15] Although hydrocracking represents the most efficient catalytic cracking process, it is also the most costly.

4.3.2.4 Catalytic Reforming

The gasolines produced from distillation and thermal cracking, as well as the heavy hydrocrackate gasoline, usually have octane numbers that are too low to meet the quality requirements for motor gasoline. Consequently, catalytic reforming is used to upgrade the octane numbers of these pools by converting their paraffinic and napthenic components into high octane number aromatic compounds. The resulting product, or reformate, is a high octane blending component for motor gasoline. Unfortunately, however, the higher the octane number of the reformate, the lower the yield and the more gases produced.

4.3.2.5 Alkylation

Alkylation is essentially the reverse of cracking, in that the process begins with smaller molecules and ends up with large ones. The light ends (olefins) produced by the cracking process, such as butylene and propylene, have boiling points too low to stay dissolved in the gasoline blends. Consequently, the olefins are combined with isobutane in the presence of a catalyst to yield a higher molecular weight isoparaffin, known as alkylate. The alkylate product has a high octane number and makes an excellent compound for motor gasoline.

4.3.2.6 Isomerization

A refinery with an alkylation unit requires a considerable supply of isobutane to match its butylene and propylene needs. This supply can be met by a hydrocracking facility, but it is more common for isomerization to be used to convert normal butane to isobutane as additional supply is required. In the isomerization process, hydrocarbon structures are rearranged in the presence of a catalyst to improve the octane number of the straight-run gasoline feed.

4.3.3 Upgrading Process

Various upgrading processes are used to improve feedstock and product quality. Hydrotreating is the most extensively used upgrading process, and is applied to a wide range of feedstocks from straight-run naphtha streams to reduced crude. The process involves stabilizing petroleum products and/or removing undesirable elements, such as sulphur, nitrogen, oxygen and trace metals, from products and feedstocks. This is achieved by reacting the feed with hydrogen in the presence of a catalyst. When the hydrotreating process is performed specifically for the removal of sulphur, it is referred to as hydrodesulphurization (HDS).

4.4 Energy Use in Petroleum Refineries

With respect to typifying energy use in petroleum refineries, the wide variations that exist among refineries in capacity and process complexity again make it difficult to arrive at an average or typical energy profile. Nonetheless, this section will present a discussion of energy use in a refinery by outlining the energy flow through the refinery, as well as noting the changes in total energy efficiencies and the potential for technological change.

4.4.1 Energy Flows and End-Use

For nearly all the processing units in a refinery, energy in the form of direct heat is required to raise the temperature of the oil being processed. Direct heat applications are carried out using two distinct groups of equipment, fired heaters for process feedstock heating and furnaces for mild or partial thermal cracking. Nearly all refinery fired heaters in Canada are dual-fired and can burn oil and/or natural gas. The processes discussed in Section 4.3 all employ fired heaters, except coking and visbreaking which require furnaces.

The fuels used in direct heat applications include: refinery fuel gas, purchased natural gas, distillate and residual fuel oils and liquefied petroleum gas (LPG). Refinery fuel gas and petroleum coke (both by-products of the distillation and cracking processes) constitute the largest portions of total energy consumption, followed by natural gas. Fuel oil is fired in heaters for processes with low feedstock preheat temperatures, such as atmospheric distillation, cat cracking and alkylation. For those processes requiring very high feedstock preheat temperatures, such as vacuum distillation, hydrocracking, catalytic reforming and hydrotreating, gaseous fuels must be fired. Coking and visbreaking furnaces also depend on firing gaseous fuels.

Additional refinery energy requirements are met by steam and electricity. Steam is used to supply power to turbines as well as to meet process and general heating requirements. Electricity is used in pump motors, fan motors and in miscellaneous uses, primarily lighting.[16] The use of cogeneration facilities in Canadian refineries is extremely limited, although electricity is frequently generated in the plant.

Table 4.3 illustrates energy consumption in the petroleum refining industry in 1987. The data on individual fuel use are expressed both in terms of total energy content and as percentage shares of total energy consumed. The most significant result from Table 4.3 is the divergence between purchased and self-produced energy. In 1987, nearly 70 percent of the fuel consumption was met by refinery product streams (i.e., refinery fuel gas, petroleum coke, residual fuel oil, distillate fuel oil and LPG). Refinery fuel gas represented the largest segment of total fuel consumption, while natural gas comprised the largest segment of purchased fuel use. The fact that relatively little distillate fuel oil was used is not surprising given its high market value relative to the other fuels.

Variations in a refinery's internal consumption of refined petroleum products will occur as a result of market induced process swings. Such swings vary the relative availability and value of distillate and residual fuel oils, refinery gas, petroleum coke and tar. Refineries may, for example switch from burning residual oil to refinery gas in dual-fuel fired heaters. Natural gas is consumed as a supplement to refinery gas to ensure a constant availability of gaseous fuels as the supply of internally produced refinery gas varies.

4.4.2 Changing Energy Efficiency and Conservation Measures

The variations in product lines and process configurations in a modern refinery indicate that there are many opportunities for improved energy efficiency. Having outlined the flow of energy through the refinery, the progress toward improved energy efficiency and the areas where conservation measures will be the most effective can be identified and evaluated.

TABLE 4.3

ENERGY USE IN THE PETROLEUM REFINING INDUSTRY 1987

Fuel Type	Petajoules	Percent of Total Consumed
Refinery Gas	127.0	43.4
Natural Gas	52.1	17.8
Distillate Fuel Oil	0.3	0.1
Residual Fuel Oil	11.7	4.0
Petroleum Coke	58.0	19.8
Electricity (Purchased)	38.9	13.3
Steam (Purchased)	2.0	0.7
Liquefied Petroleum Gas	2.6	0.9
Totals	292.6	100.0

SOURCE: Canadian Industry Program for Energy Conservation, 1987 Reports (Ottawa: Department of Energy, Mines and Resources, 1988).

In 1987, the CIPEC Petroleum Refining Industry Task Force reported that total energy consumption was 30.5 percent lower than in the 1972 base year. This surpassed the target of a 30 percent improvement in energy efficiency by 1990. The 4.9 percent improvement in energy consumption from 1985 was a significant reduction, considering the greatly reduced capital expenditures and lower expected rates of return on potential energy conservation projects resulting from the 1986 fall in world oil prices. In contrast to CIPEC's efficiency calculations for the pulp and paper industry which do not include the use of waste fuels, petroleum refineries reporting to CIPEC do include the use of wastes in their energy consumption. The participation of Canadian refiners in CIPEC is considerable, with approximately 90 percent of the crude oil upgraded and refined in Canada being represented in 1987.[17]

Two notable features of energy use in the petroleum refining industry have been the proportionate increases in the use of refinery fuel gas and petroleum coke. The amount of refinery fuel gas consumed as a percentage of total energy use has increased from 37.7 percent in 1985 to 43.4 percent in 1987. This upward trend is expected to persist as a result of the continued lead phasedown, since more energy is required to produce unleaded gasoline. The percentage use of petroleum coke has increased each year since 1982, with an average annual growth rate of 1.2 percent. With the change in demand patterns favouring lighter products, the throughputs to refinery cat crackers have been greatly increased, and the fluid catalytic cracking (FCC) units driven harder, in order to maximize the light-end yield. The increased cat cracking activity also results in more coke being deposited on the catalyst as a by-product. This additional coke is burned off in the unit, providing a large amount of process heat, and accounts for petroleum coke's increasing share of total energy use.

With regard to potential energy conservation projects, weakened crude oil and product prices have severely limited investment decisions. As a result, the outlook for energy conservation measures in the short term remains moderate until crude prices recover. Improvements in process control and optimization, as well as further improvements in operating and maintenance procedures, will continue to lead the way toward additional reductions in energy use. Smaller investment projects that will help contribute to increased energy efficiency include investments in waste heat recovery facilities and automated systems support. Other effective areas for investment in energy conservation include: modifications to raise furnace and boiler efficiencies, reduction in steam consumption, and facilities to reduce fuel gas production (for details see earlier process description in Chapters 2 and 3). In the long term, further progress in energy efficiency in the refining industry will necessitate larger capital expenditures.

4.4.3 Technological Change in Petroleum Refining

As reported at the 1987 World Petroleum Congress, the major challenge to refineries in the long term will be their ability to adjust refinery operations to frequently changing crude and product markets.[18] The degree to which refiners actually succeed in enhancing this ability will largely be determined by the development and proper application of new technology.

The type of technology undergoing the most rapid development and application in response to continued octane production needs is catalytic improvement. From 1985 to 1987, more than 400 new petroleum-refining industry catalysts were introduced, increasing the total number of available refining catalysts to more than 1000. Of the catalysts added, the majority represented new fluid catalytic cracking (FCC) catalysts. In fact, 45 of the 94 catalysts introduced in 1987 were FCC catalysts.[19]

The development of these new FCC catalysts is characterized by a movement away from bulk, general purpose catalysts to more customized, specialty catalysts.[20] Customized catalyst formulations provide refiners with higher octane and greater gasoline yields, as opposed to the typical tradeoff between octane and yield. Recent developments have also provided refiners with a framework for evaluating the various commercial catalysts available. This framework enables refiners to select catalysts that move the FCC operation nearer to process objectives.[21]

In the long term, the quality of crude feedstock entering refineries will continue to decline, and the industry will have to adapt to processing heavier fuel oils. As a greater quantity of heavy crude must be processed in order to yield a given amount of gasoline, refineries will need to modify their capacity to handle this heavier crude slate. The recent approval of the Husky Oil-operated, heavy oil upgrader project at Lloydminster represents a step in this direction. Furthermore, as the availability of light crude oil decreases, synthetic crude oil will play an increasingly important role in the Canadian refining industry.[22] The challenges associated with processing synthetic crude oil will also demand further process flexibility and adaptability.

In view of these trends toward heavier crude slates and synthetic crude processing needs, hydrocracking facilities represent the vehicle of technological change. The versatility of the hydrocracking process with respect to heavy fuel oils was discussed in Section 4.3.2. Synthetic crude can be cracked in a cat cracker in conventional refineries, but hydrocracking is a far more efficient process. The processing of synthetic crude is characterized by swings in yield and product quality, but the use of a hydrocracking unit provides a higher yield and a better quality product.

The current obstacle encountered in implementing this form of technology is that hydrocracking units have large capital requirements. Not only is the unit itself very expensive, but investment in this process often implies an investment in a hydrogen production plant as well.[23] Until crude oil and product prices firm up sufficiently to increase refinery margins, as well as guarantee adequate expected rates of return, the necessary capital funds will likely not be available. As is the case for all upgrading projects, the economics depends on the differential between heavy crude and light-end product prices, rather than the crude price alone.

Another challenge facing refiners is the federal government's announcement of an accelerated timetable for the phase-out of lead from gasoline. The advancement of the deadline for the ban on leaded gasoline from January 1, 1993 to December 1, 1990 has sent refiners scrambling for immediate means of enhancing octane values. Clearly, given the shorter time span they must now work within, refiners cannot wait for the penetration of new technologies. Rather, options which can be implemented quickly and effectively warrant the most attention.

In this regard, refiners have essentially two options: install new equipment such as additional isomerization processes to enhance octane quality, or replace lead with environmentally acceptable additives. A number of refineries have already adopted the former solution and have either revamped existing isomerization processes or added new equipment. Still, these procedures are not inexpensive and the phase-out could cost refiners between $500 million and $1 billion in capital.[24]

In the long term, the potential for technological change is greater. One potentially fundamental process change involves production of gasoline directly from natural gas feedstocks instead of crude oil. Currently, considerable amounts of capital are being devoted abroad to research and development of this option with the expectation that the technology will be available by 1995.[25] New Zealand has come close to commercializing this technology, having built and operated since 1986 the world's only natural gas-to-methanol-to-gasoline plant. The implementation of such a technology remains doubtful, however, even if oil prices were to rise substantially. Natural gas-based gasoline would have to compete for commercial viability against a host of alternative transportation fuels with established, and constantly advancing, technologies such as compressed natural gas (CNG), liquified natural gas (LNG), methanol, ethanol and MTBE.[26] These alternative transportation fuels all represent back-stop technologies at higher oil prices, and advancing production processes are continually lowering the back-stop price. In order for such technologies to be commercially viable, the crude oil price would have to rise to the $30 to $33 (U.S.) range.[27] This will only occur in the last decade of the forecast period according to the projection for this study, limiting large-scale substitution away from conventional transportation fuels. However, growing environmental concerns may accelerate this development.

4.5 Conclusions

The direction of technological change in the refining industry will be product driven. The demand for higher octane at the retail level, the accelerated schedule for the phasedown of lead in 1990 and increased product desulphurization requirements have all increased refiners' efforts to obtain new technologies that increase process and product mix flexibility. Major avenues of change in this regard include: improved catalysts, advanced computer control and process optimization techniques, and sophisticated data management systems. Increased demand for light-end, high octane products will initially put pressure on refiners' cat cracking facilities, and eventually lead to increased investment in hydrocracking and isomerization capacity for conversion, and increased upgrading by hydrotreating.

As cat crackers are driven harder to produce more light-end products, larger volumes of refinery fuel gas become available, increasing the potential displacement of natural gas by refinery gas. In addition, as crude and product prices firm up, continued investment in new technologies and conservation measures will be warranted.

Sizable gains in energy efficiency can be made by continuing to supplant purchased natural gas with self-produced refinery fuel gas.

Footnotes

[1] Canadian Petroleum Association, Statistical Handbook (Calgary: Canadian Petroleum Association, April 1987), Section VIII, Table 7.

[2] Statistics Canada, Refined Petroleum Products, Catalogue No. 45-004, December 1986 (Ottawa: Ministry of Supply and Services Canada, March 1987), Table I, p. 96.

[3] Statistics Canada, Refined Petroleum and Coal Products, Catalogue No. 45-250 (Ottawa: Ministry of Supply and Services Canada, January 1988), Table I, p. 8.

[4] The Canadian capacity figure includes synthetic crude oil facilities in Alberta, and was obtained from the Canadian Petroleum Association, Statistical Handbook (Calgary,: Canadian Petroleum Association, June 1987), Section VIII, Table 3B. The U.S. figure was taken from Oil and Gas Journal Data Book: 1987 Edition (Tulsa: PennWell Publishing Company, 1987), p. 171. The Japanese figure was taken from Oil and Gas Journal Data Book: 1986 Edition (Tulsa: PennWell Publishing Company, 1986), p. 184.

[5] Ibid., pp. 184-185.

[6] Statistics Canada, Refined Petroleum Products, p. 96.

[7] Canadian Petroleum Association, Statistical Handbook, Section VIII, Table 6.

[8] Ministry of Supply and Services Canada, Competition in the Canadian Petroleum Industry (Ottawa: Ministry of Supply and Services, 1986).

[9] James H. Gary and Glenn E. Handwerk, Petroleum Refining (New York: Marcel Decker, Inc., 1975), p. 31.

[10] Leonard Nakamura, "Chapter 18 - Petroleum Refining in United States," The Conference Board, Energy Consumption in Manufacturing (Cambridge, Mass.: Ballinger Publishing Company, 1974), p. 316.

[11] Ministry of Supply and Services Canada, Competition in the Canadian Petroleum Industry, p. 205.

[12] Micheal O. Lerner; Arun Sarin; and Vivendra S. Kothari, Industrial Energy Use: Volume II (Arlington, Va.: Energy Environmental Analysis, Inc., January 1982), p. V-2.

[13] Gary and Handwerk, Petroleum Refining, p. 86.

[14] Ibid., p. 121.

[15] Kirk-Othmer, *Concise Encyclopedia of Chemical Technology*, Volume 26, Third Edition (New York: John Wiley & Sons, Inc., 1985), p. 856.

[16] A. F. Rupp and E. M. Rupp, "Chapter 14 - Petroleum Refining," in Oakridge Associated Universities, *Industrial Energy Use Data Book* (New York: Garland STPM Press, 1980), p. 14-6.

[17] Canadian Industry Program for Energy Conservation, *1987 Taskforce Report* (Ottawa: Department of Energy, Mines and Resources, 1986), p. 53.

[18] *Oil and Gas Journal*, "World Petroleum Congress - Report No. 2," May 11, 1987, pp. 33-36.

[19] Richard A. Corbett, "Worldwide Catalyst Report," in *Oil and Gas Journal Data Book: 1988 Edition* (Tulsa: PennWell Publishing Company, 1987), p. 148.

[20] Ibid.

[21] Charles C. Wear and Raymond W. Mott, "FCC Catalysts Can Be Developed for Optimum Performance" in *Oil and Gas Journal*, July 25, 1988, p. 71.

[22] John E. Devai, Gregory H. Lenz and Brian E. Schoenroth, "Synthetic Crude Oil and the Canadian Refiner," paper presented to the Third District Five Meeting, Canadian Institute of Mining and Metallurgy (Fort McMurray, Alberta: September 16-19, 1987), pp. 1-2.

[23] D. Baillard-Haurie, C. Berger, A. Haurie, and R. Loulou, *A Markal Model of the Long Range Evolution of the Refining Industry: The Case of Quebec* (Montreal: GERAD, 1987), p. 65.

[24] *Oilweek*, "Refiners Rushing to Meet Earlier No-lead Deadline," September 19, 1987, p. 7.

[25] United States, Department of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector*, Progress Report One: Context and Analytical Framework (Washington: Department of Energy, January 1988).

[26] Michelle Heath, *Towards a Commercial Future: Methanol and Ethanol As Alternative Transportation Fuels*, Canadian Energy Research Institute, Study No. 29 (Calgary: Canadian Energy Research Institute) January 1989.

[27] "Ethanol and Methanol in a Changing Transportation Fuel Market," *World Oil Market Analysis*, vol. VII, no. 1 (Calgary, Alberta: Canadian Energy Research Institute, January 1989).

Chapter 5

THE CHEMICAL AND CHEMICAL PRODUCTS INDUSTRIES

The industrial chemicals sector, SIC code 371, is the largest 3-digit sub-group of the chemical and chemical products industries, both in terms of cost of fuel and electricity and in terms of value of shipments. The agricultural chemicals sector, SIC 372, is the second largest subsector in terms of purchased fuel and electricity.[1] Unlike the manufacturing industries in the previous chapters, where it was possible to present a discussion on energy use entirely on the 3-digit industry level, a meaningful discussion of energy use in the industrial chemicals sector requires further disaggregation. The principal reason for this disaggregation is the number of products of the industry. Given that the industry produces more than 100 industrial chemicals, a general category does not afford an accurate understanding of the industry's diversity.

In response to this, two related methods of disaggregation are currently used. The SIC code divides industrial chemicals into two 4-digit sub-segments: inorganic chemical industries (SIC 3711) and organic chemical industries (SIC 3712). Alternatively, the Canadian Chemical Producers' Association (CCPA) divides industrial chemicals into four categories: inorganic chemicals, petrochemicals, organic and specialty chemicals and fertilizer chemicals. The petrochemical and organic and specialty chemicals categories are sub-divisions of the organic chemicals sector. Because the organic and specialty chemicals industry is a very small natural gas user relative to the larger petrochemical sector, it will not be considered in this study. With regard to the fertilizer chemicals category, the CCPA defines it as being comprised of industrial chemicals used solely for the production of fertilizers. On the other hand, the SIC code includes fertilizer chemicals separately as a sub-segment of the 3-digit agricultural chemicals sector.

A similar clarification regarding sub-sectors is required for the agricultural chemicals sector, which is the second largest 3-digit natural gas consumer of the chemical and chemical products industries. Actually, it is the chemical fertilizer sub-segment, SIC code 3721, that represents virtually all of the natural gas used in this sector. Therefore, consistent with this study's focus on industrial natural gas demand, the chemical fertilizer sub-segment will represent the agricultural chemicals sector. This delineation is consistent with the definition of the Canadian basic fertilizer industry as specified by the Canadian Fertilizer Institute. The other two 4-digit sub-segments, mixed fertilizers and other agricultural chemicals, account for less than 1 percent of natural gas use in the sector.

In summary, then, the chemical industries considered in this chapter will be:

- the petrochemical industry,
- the inorganic chemicals industry, and
- the fertilizer industry.

5.1 Size and Significance of Canada's Chemical Industries

The importance of the chemical industry is derived from the interdependence of chemical products with other manufacturing industries. The majority of the industry's products are intermediate goods for use in other industries. Essentially all Canadian manufacturing industries employ chemicals to process their own materials. Industries in which chemicals are widely used include: pulp and paper, paint, rubber and packaging.

In 1985, the $18.3 billion value of shipments for Canada's chemical industries ranked fourth behind transportation and equipment industries, food industries, and refined petroleum and coal products industries. The largest subsector, industrial chemicals, generated 38 percent of these shipments, while agricultural chemicals accounted for 8 percent.[2]

On the international front, Canada is a major contributor of manufactured chemicals, with export sales totalling more than $3.3 billion in 1987. The majority of Canadian chemicals exports, greater than 64 percent averaged over products in 1987, are shipped to the United States. Capacity utilization in the chemical and chemical products industries fell to 71.9 percent in the 1982 recession, and recovered to average 89.5 percent in 1987.[3]

5.1.1 The Petrochemical and Inorganic Chemicals Industries

The industrial interdependence that distinguishes the role of the chemical industries in the national economy is especially pertinent to the petrochemical and inorganic chemicals industries. The operations of many major Canadian manufacturing industries, such as pulp and paper production, mineral and metal processing, and petroleum refining, require an assured supply of inorganic chemicals. Similarly, operations in the plastics, textiles and rubber industries are major consumers of petrochemicals.

The major inorganic chemicals produced include: chlorine, sodium hydroxide (or caustic soda), sulphuric acid, ammonia, nitrogen, oxygen, sodium chlorate and nitric acid. The primary petrochemical products include: the olefins (ethylene, propylene, butadiene), the aromatics (benzene, toluene, xylenes) and methanol. Table 5.1 lists selected inorganic and petrochemical products in terms of shipment tonnes and value in 1985. The total value of shipments in 1985 was $2.2 billion for the inorganic chemical industries and $4.7 billion for the organic chemical industries.[4] Total end product sales for the petrochemical industry alone were $4.2 billion.[5]

The Canadian petrochemical industry is particularly important in both the national and international economy. The development of world-scale petrochemical facilities allows for a considerable share of production to be placed on the international market. For example, almost 90 percent of Canadian methanol production is available for export. As Figure 5.1 illustrates, Canada accounts for 11.6 percent of the world's methanol production. Relative to installed ethylene capacity, Canada ranked seventh in the world in 1985 behind the U.S., Japan, West Germany, France, the Netherlands and the U.K.[6] The bulk of Canadian petrochemical exports, 58 percent in 1987, are shipped to the U.S.[7] Similarly, 84 percent of Canadian inorganic chemical exports was delivered to the U.S market in 1985.[8]

Compared to other chemical industries, Canada's petrochemical and inorganic sectors recovered well from the 1982 recession. The petrochemical industry's capacity utilization fell to 74 percent in 1982, and had increased to 95 percent by 1987, while capacity utilization in the inorganic sector fell to 72 percent, and recovered to 90 percent in 1986, declining to 84 percent in 1987.[9]

TABLE 5.1

SELECTED INORGANIC CHEMICALS AND PETROCHEMICALS SHIPMENT QUANTITY AND VALUE
1985

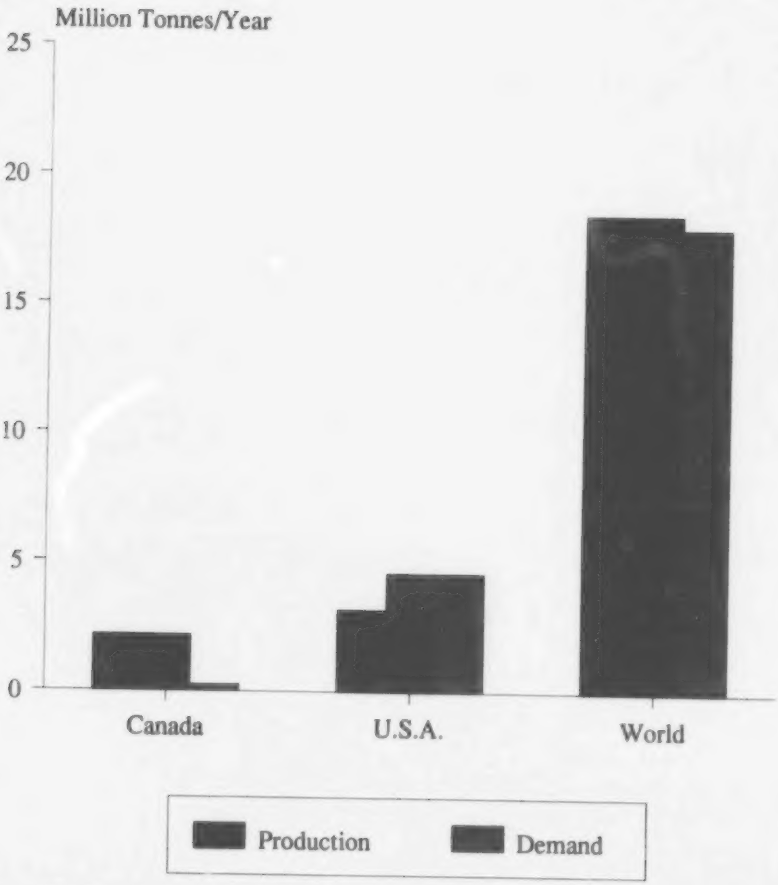
Industrial Chemical Commodity	Quantity[a] (tonnes)	Value ($000)
Inorganic:		
Sodium Hydroxide (Liquid)	1 319 430	233 883
Chlorine	805 937	138 007
Inorganic acids[b]	--	141 671
Oxygen	--	80 257
Nitrogen	--	45 521
Petrochemical:		
Methanol	2 218 716	225 715
Ethylene	1 859 202	852 670
Benzene	545 649	269 856
Toluene	449 876	164 941
Xylene	416 184	151 851
Butadiene	147 503	95 175

SOURCE: Statistics Canada, Chemical and Chemical Products Industries, Catalogue No. 46-250, Annual (Ottawa: Statistics Canada, 1985), Table 2.

[a] Missing quantity data were not available from Statistics Canada publications due to secrecy requirements of the Statistics Act.

[b] More specifically this refers to inorganic acids and oxygen compounds of non-metals or metalloids. Sulphuric acid and nitric acid are included in this group.

Figure 5.1
Methanol Production/Demand



Source: Canadian Oxygenated Fuels Association Presentation to Canadian Gas Association, May 18, 1988.

5.1.2 The Fertilizer Industry

Whereas petrochemicals and inorganic chemicals are linked to the performance of other manufacturing industries, the fertilizer industry is dependent on the health of the agricultural sector. On the national level, expectations about crop planting and natural occurrences that affect agricultural output, such as bumper crops or severe droughts, greatly influence fertilizer demand and production. More importantly, on the international level the Canadian fertilizer industry is significantly affected by the over-capacity and subsidy schemes that characterize the world grain markets. Such subsidization policies include the U.S. acreage reduction initiatives, and the European Economic Community's Common Agricultural Policy (CAP).

Most of the major fertilizer chemicals are ammonia derivatives, including: nitric acid, ammonium nitrate, urea ammonium sulphate and ammonium phosphate. One other primary fertilizer chemical, wet process phosphoric acid, is obtained from reacting sulphuric acid with phosphate rock. Table 5.2 illustrates shipment tonnes and value for selected fertilizer chemicals in 1985. The total value of shipments for the chemical fertilizer industry in 1985 exceeded $966 million.[10]

TABLE 5.2

SELECTED FERTILIZER CHEMICALS
SHIPMENT QUANTITY AND VALUE
1985

Chemical Fertilizer Commodity	Quantity[a] (tonnes)	Value ($000)
Ammonia	1 616 535	260 311
Urea	1 417 824	222 095
Ammonium Phosphate, fertilizer grade	--- ---	280 730
Ammonium Nitrate, fertilizer grade	499 196	78 455

SOURCE: Statistics Canada, Chemical and Chemical Products Industries, Catalogue No. 46-250, Annual (Ottawa: Statistics Canada, 1985), Table 2.

[a] Missing quantity data and data for additional commodities were not available due to secrecy requirements of the Statistics Act.

The Canadian fertilizer industry is a major player on the international market, with annual production far in excess of domestic requirements. More than 70 percent of the total Canadian sales volume in tonnes was exported in 1985. Total export sales volumes for the Canadian fertilizer industry exceeded 12 million tonnes in 1985, with a total value of $1.1 billion.[11]

5.2 Regional Supply of Chemical Products

The primary factors affecting the supply of chemical products are the cost and availability of raw materials, the location of these materials relative to large customer industries, and the performance of the customer industries.

5.2.1 Raw Material Requirements

The major raw materials required to produce petrochemicals are crude oil and natural gas. Crude oil fed to petroleum refineries is refined to naphtha, refinery fuel gas and gas oil which in turn become feedstocks for the petrochemical industry. Natural gas is piped to petrochemical plants and provides a number of petrochemical feedstocks, including methane, ethane and natural gas liquids (i.e., propane, butane and pentane-plus). Consequently, the petrochemical industry joins petroleum refineries as being unique among Canadian manufacturing industries in using hydrocarbon resources principally as raw materials, rather than as sources of energy.

In the production of inorganic chemicals, the basic raw materials required are minerals, metals and salts. Three of the major inorganic chemicals, chlorine, caustic soda and sodium chlorate, are derived from electrolysis of salt. Sulphuric acid, one of the most versatile inorganic chemicals, is derived from sulphur recovered from either sour natural gas or from waste gases produced during ore smelting. In addition, gases produced in metal and petroleum refining processes are used to manufacture other inorganic chemicals.

The basic feedstock required to produce fertilizer chemicals is the inorganic chemical ammonia. Although ammonia is produced from natural gas, it is not a petrochemical. Rather, ammonia is generally classified as an agricultural chemical. Two other mined raw materials, phosphate and potash, are also important in fertilizer production. Wet process phosphoric acid and potassium oxide contained in potash can either be applied directly as fertilizers, or mixed with other fertilizer chemicals.

The petrochemical, inorganic chemicals and fertilizer industries have all been classified as large energy users. Specifically, the inorganic chemicals industry is one of Canada's largest users of electricity, whereas the petrochemical and fertilizer industries represent two of the largest natural gas users. The distinction between purchased and self-produced energy is important also for the petrochemical and inorganic chemicals industries. A considerable amount of the process energy required in these two industries can be produced from plant wastes or process by-products. Furthermore, a significant amount of the electricity required by these industries is self-generated.

5.2.2 Regional Development

There are two underlying trends governing the regional development of chemical industries. First, chemical plants are generally located close to the origin of their respective raw materials in order to ensure a secure and economical supply. Examples of this trend include:

- development of inorganic chemical plants in Quebec and B.C. due to the availability of inexpensive electric power;
- a larger share of petrochemical plants in Alberta and Ontario as a result of readily available hydrocarbon resources, with natural gas comprising the primary feedstock for Western Canadian petrochemical producers, and oil-based raw materials comprising the principal feedstock for Eastern Canada; and
- the majority of ammonia and fertilizer plants being located in Alberta because of the inexpensive, secure supply of natural gas.

The regional distribution of petrochemical and fertilizer plants in Canada is illustrated in Tables 5.3 and 5.4, respectively.

From Table 5.3, the magnitude of the petrochemical plants in Alberta is evident. While Alberta has two fewer plants than Quebec, the annual capacity of the plants in Alberta is nearly three times that of the Quebec plants. Furthermore, while Alberta has only half as many plants as Ontario, Alberta's annual capacity is only 15 percent less than that of Ontario. Three plants account for 75 percent of Alberta's annual capacity: Alberta Gas Ethylene (32 percent), Celanese Canada Inc. (24 percent) and Alberta Gas Chemicals (19 percent).[12] Alberta Gas Ethylene is the largest volume petrochemical plant in Canada, while Alberta Gas Chemicals and Celanese Canada Inc. represent two of only three methanol plants in Canada. The third methanol plant (Ocelot Industries Ltd.) is located in Kitimat, B.C., and

TABLE 5.3

REGIONAL DISTRIBUTION AND CAPACITIES OF PETROCHEMICAL PLANTS
1987

	No. of Plants	Annual Capacity[a]	
		(tonnes)	(percentage of total)
Atlantic	1	16 783	(-)
Quebec	13	1 404 948	14
Ontario	22	4 554 652	44
Prairies[b]	11	3 864 403	37
B.C.	5	519 700	5

SOURCE: "Refinery and Petrochemicals Report," Oilweek, June 8, 1987, vol. 38, no. 19, p. 7.

[a] Oilweek includes annual capacity data for ammonia, fertilizer chemicals, and some inorganic chemicals in its petrochemical industry classification. Data for these categories are not included in the regional totals presented.

[b] Alberta accounts for all Prairies figures.

TABLE 5.4

REGIONAL DISTRIBUTION OF CHEMICAL FERTILIZER PLANTS

1987

	Ammonia	Urea	Ammonium Sulphate	Ammonium Nitrate	Ammonium Phosphate	Phosphoric Acid
Atlantic	--	--	--	--	1	1
Quebec	--	--	--	1	--	--
Ontario	3	1	--	2	--	--
Prairies[a]	10	5	2	4	2	2
B.C.	2	--	1	--	1	1

SOURCE: Canadian Fertilizer Institute, Fertilizer Production Capacity Data--Canada, revised September 1987 (Ottawa: CFI, 1987).

[a] Aside from Manitoba representing one plant in each of the following categories: ammonia, urea and ammonium nitrate, Alberta accounts for all Prairies figures.

its annual capacity of 445 300 tonnes constitutes 86 percent of the total annual petrochemical capacity in that province.[13] The dominant role played by Alberta in the Canadian fertilizer industry is clearly shown in Table 5.4.

The second underlying trend in the regional development of chemical plants is their location relative to large customer industries. Because chemicals and chemical products are largely intermediate goods, the competitiveness of customer industries also depends on a secure and economical supply of chemicals and chemical products. The most salient example of this is the location of inorganic plants near major facilities in the pulp and paper industry in B.C.

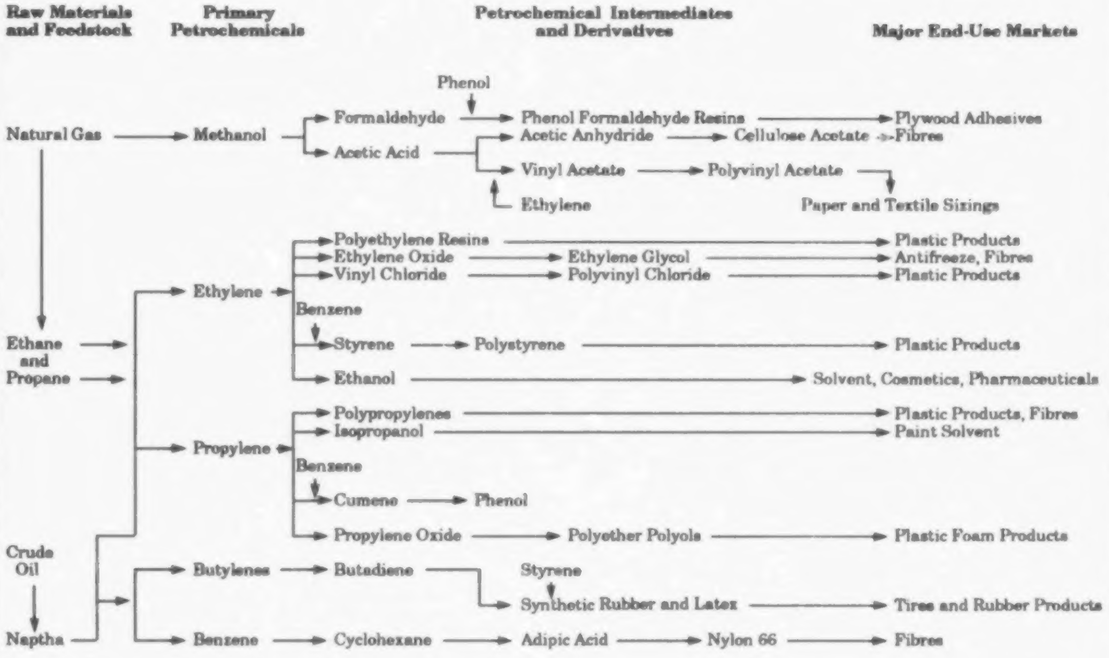
5.3 Production Processes

Because of the diversity of the chemical industries, there are simply too many chemicals and processes involved to permit complete and thorough individual analyses. Consequently, process descriptions for the petrochemical and fertilizer industries will be limited primarily to those chemical processes that are largely dependent on natural gas, both as a feedstock and as a fuel. As for the inorganic chemicals industry, the chemical processes discussed will include those for the industry's two major products, chlorine and caustic soda, as well as those for sodium chlorate and selected inorganic acids.

5.3.1 Petrochemical Processes

The two petrochemical processes that depend on natural gas to the largest extent are the production of olefins and the production of methanol. Ethylene is the principal olefin produced and, because of its chemical versatility, is regarded as the most important building block of the petrochemical industry. Methanol, on the other hand, represents the largest volume petrochemical produced in Canada and accounts for a considerable amount of the chemical industry's direct consumption of natural gas. Indeed, the methanol production process is itself entirely dependent on natural gas, both for feedstock and process heat. One petrochemical process that is not dependent on natural gas is aromatics production. Aromatics are derived primarily from the refining of petroleum, but will be included in this section because they are also produced as a by-product of the ethylene process. Figure 5.2 illustrates the relationship between these petrochemical products.

Figure 5.2
Relationship Between Selected Petrochemical Products


Raw Materials and Feedstock
Primary Petrochemicals
Petrochemical Intermediates and Derivatives
Major End-Use Markets
Natural Gas
Methanol
Formaldehyde
Phenol
Phenol Formaldehyde Resins
Plywood Adhesives
Acetic Acid
Acetic Anhydride
Cellulose Acetate
Fibres
Vinyl Acetate
Polyvinyl Acetate
Ethylene
Paper and Textile Sizings
Polyethylene Resins
Plastic Products
Ethylene Oxide
Ethylene Glycol
Antifreeze, Fibres
Vinyl Chloride
Polyvinyl Chloride
Plastic Products
Ethylene
Benzene
Styrene
Polystyrene
Plastic Products
Ethane and Propane
Ethanol
Solvent, Cosmetics, Pharmaceuticals
Polypropylenes
Plastic Products, Fibres
Isopropanol
Paint Solvent
Propylene
Benzene
Cumene
Phenol
Propylene Oxide
Polyether Polyols
Plastic Foam Products
Crude Oil
Butylenes
Butadiene
Styrene
Synthetic Rubber and Latex
Tires and Rubber Products
Naptha
Benzene
Cyclohexane
Adipic Acid
Nylon 66
Fibres

SOURCE: Texaco Canada Inc., Energy and Economic Data Book 1987-88, p. 222.

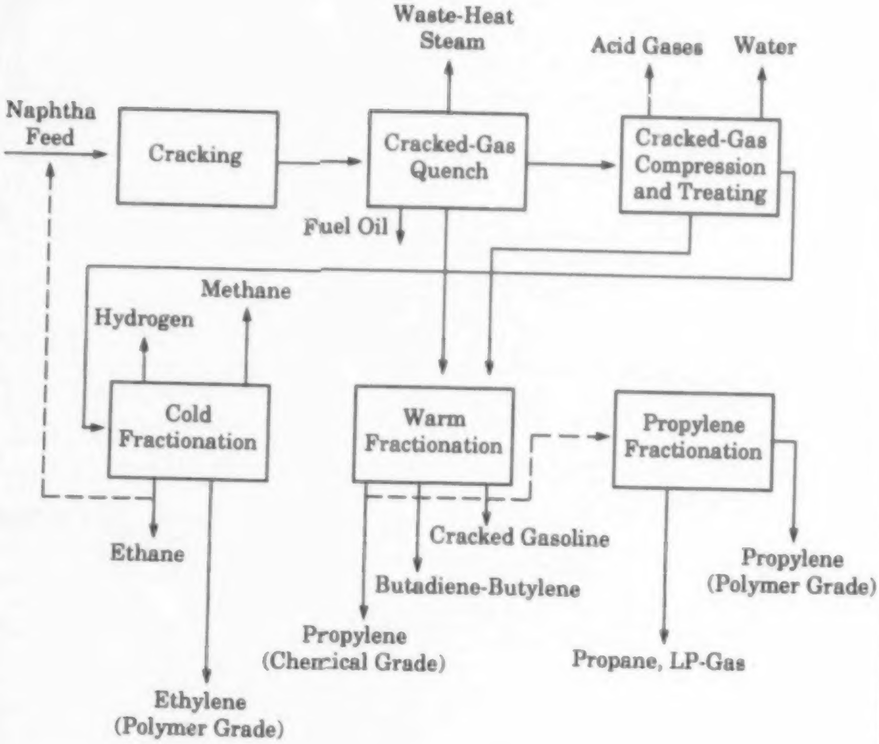
5.3.1.1 Ethylene

The production of ethylene involves the steam cracking (or pyrolysis) of either single-component natural gas feeds, such as ethane or propane, or multicomponent hydrocarbon feeds, such as naphthas, gas oils and natural gas liquids. Of the four large ethylene production facilities in Canada, the Alberta Gas Ethylene plant in Alberta and the Petromont plant in Quebec produce ethylene from ethane, while the Polysar and Esso plants in Ontario produce ethylene from naphtha, gas oils and propane.[14] Figure 5.3 presents a process flow diagram for a typical ethylene refinery. Whether the feed to the ethylene plant is ethane, naphtha, or heavy gas oils, the same process scheme depicted in Figure 5.3 is used, with very minor modifications required for the different feeds. The major difference observed is in the amount and type of higher molecular weight by-products produced.

The pyrolysis of the hydrocarbon feed occurs in tubular reactor coils at high temperatures and low pressures. The cracked-gas products are then charged to a quench tower, where the heavier fuel oil and aromatics-rich pyrolysis gasoline products are separated. The remaining gases are resolved into high outputs of ethylene and propylene by compression in conjunction with condensation and fractionation at gradually lower temperatures. Given the limited demand for propylene in comparison to the increasing demand for ethylene, the amount of propylene produced is kept within certain limits.

A number of factors affect the yield of ethylene from the pyrolysis process. For example, by increasing the cracking severity and/or lowering the cracking coil residence time, the ethylene yield increases substantially. Preferential production of ethylene is also achieved by recycling ethane, propylene or propane. A further factor affecting ethylene yield is the hydrogen-to-carbon (H/C) ratio, by weight, of the feedstock used. Lighter feedstocks, such as ethane and propane, have higher H/C ratios than their heavy counterparts, naphtha and gas oils. Ethylene yield increases with increased cracking severity, as does the production of hydrogen and methane. Because hydrogen and methane have the highest H/C ratios of all cracked products, a surplus of carbon results and the formation of carbonaceous coke and tar is increased. This coking problem lowers the efficiency of the pyrolysis heater. The low H/C ratio feeds--such as naphtha and gas oils--crack at lower temperatures, and thus the coking problem materializes sooner and to a greater extent as the severity of the process is increased. As a result, ethylene yields from

Figure 5.3
Process Flow Diagram for a Typical Ethylene Plant


Waste-Heat Steam
Acid Gases
Water
Naphtha Feed
Cracking
Cracked-Gas Quench
Cracked-Gas Compression and Treating
Fuel Oil
Methane
Hydrogen
Cold Fractionation
Warm Fractionation
Propylene Fractionation
Ethane
Cracked Gasoline
Butadiene-Butylene
Propylene (Chemical Grade)
Propylene (Polymer Grade)
Propane, LP-Gas
Ethylene (Polymer Grade)

SOURCE: Petroleum Publishing Co., 1976, p. 54.

ethane pyrolysis are considerably greater than those obtained from naphtha cracking.

5.3.1.2 Aromatics

The primary source of aromatics (benzene, toluene and xylenes) is the catalytic reforming of naphtha in petroleum refineries. Refineries use aromatics as high octane blending components for motor gasoline and constitute the primary supplier of aromatics to the petrochemical industry. As the phaseout of lead in the manufacture of gasoline continues, the demand for aromatics from the refinery end will increase, and the supply of these basic petrochemicals to the petrochemical industry will be constrained. Therefore, alternative sources of aromatics will become increasingly important.

One major alternative source of aromatics is from pyrolysis gasoline, the aromatics concentrate obtained as a by-product of steam cracking of ethane to produce ethylene. Even larger quantities of pyrolysis gasoline are obtained from naphtha and gas oil cracking for ethylene production. Typical pyrolysis gasoline may contain as much as 70 percent aromatics by weight, about half of which is benzene.

Aromatics are recovered from pyrolysis gasoline in a combination of several process steps, beginning with hydrogenation and desulphurization. Hydrogenation involves the saturation of the large proportion of olefins contained in the pyrolysis gasoline. Desulphurization is used as most of the residual sulphur in the olefin-plant feed is concentrated in the pyrolysis gasoline. Following these initial processes, the aromatics are separated from the remaining non-aromatics by solvent extraction, and then the aromatics-rich concentrate is fractionated to yield the individual aromatic compounds.

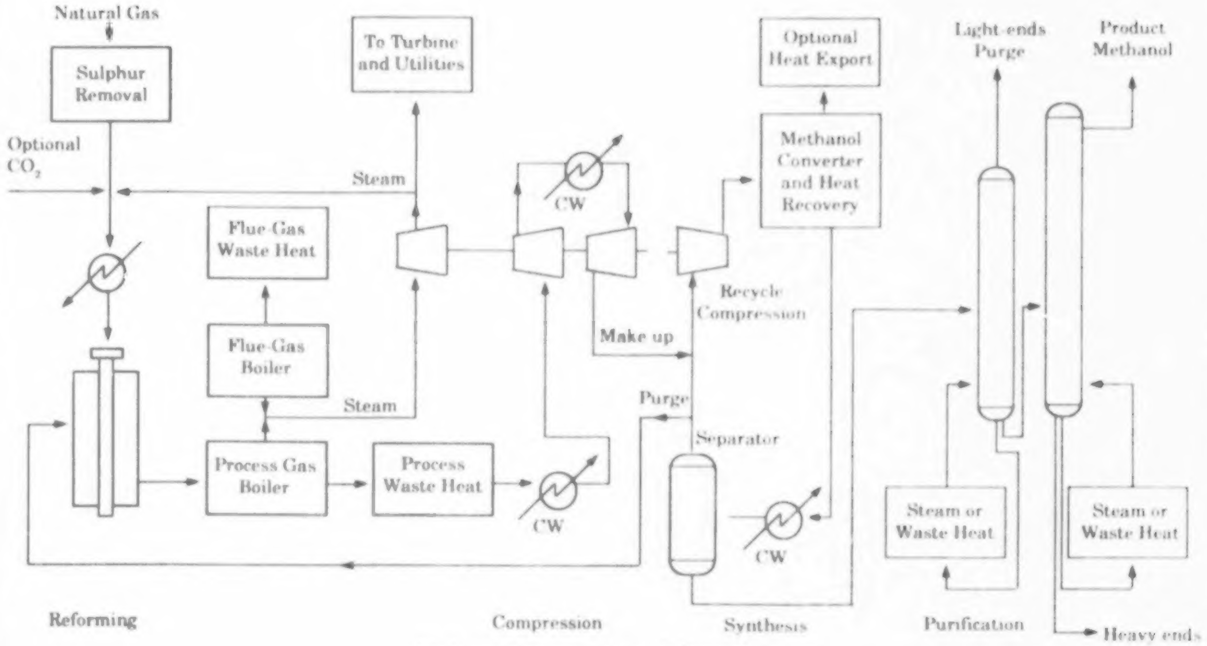
5.3.1.3 Methanol

The basic steps involved in production of methanol can be summarized as follows:

- steam reforming of natural gas plus the addition of carbon dioxide (CO_2),
- compression,
- synthesis, and
- purification.

Figure 5.4 illustrates a schematic overview of these processes.

Figure 5.4
Methanol from Natural Gas


Natural Gas
Sulphur Removal
Optional CO₂
To Turbine and Utilities
Steam
Flue-Gas Waste Heat
Flue-Gas Boiler
Steam
Process Gas Boiler
Process Waste Heat
CW
CW
Make up
Recycle Compression
Purge
Separator
CW
Optional Heat Export
Methanol Converter and Heat Recovery
Light-ends Purge
Product Methanol
Steam or Waste Heat
Steam or Waste Heat
Heavy ends
Reforming
Compression
Synthesis
Purification

Methanol from natural gas. CW = cooling water.

SOURCE: Kirk-Othmer, 1985, Volume 26, Third Edition, p. 758.

Following the initial desulphurization process, the natural gas feed is charged to a reforming furnace and mixed with steam in the presence of a nickel-based catalyst to produce synthesis gas--a mixture of carbon monoxide (CO) and hydrogen (H_2). Because natural gas is mostly methane, with a carbon to hydrogen (C-H) ratio of 1-4, and given that the optimum C-H ratio for methanol production is 1-2, the addition of CO_2 is required to react with the surplus hydrogen and increase the methanol yield.

Once the correct composition of synthesis gas is obtained, the synthesis gas is cooled, compressed and then fed to a catalytic converter where the actual synthesis of methanol occurs. The converter itself is a steel vessel packed with a metallic heterogeneous catalyst. The activity of the particular catalyst used dictates the required synthesis pressure. For example, chromium oxide-zinc oxide catalysts require high pressure, whereas copper-based catalysts permit operation at low pressure. The final step involves the purification of the crude methanol by distillation. The crude methanol product from the converter is charged to a pair of boilers, or distillation units, where it is heated and the light- and heavy-end impurities are separated and removed, yielding a pure methanol residual.

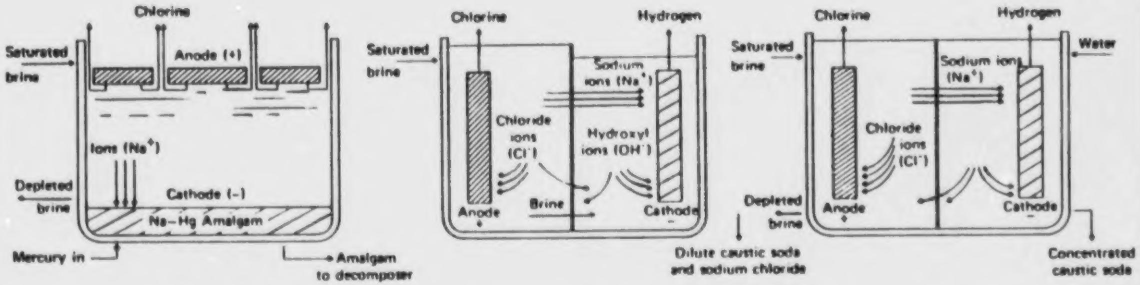
5.3.2 Inorganic Chemical Processes

The nature of the chemical processes involved in the manufacture of inorganic chemicals is such that the principal energy requirement is electric power. For example, the production of the two largest volume inorganic chemicals, chlorine and caustic soda, is entirely dependent on the electrolysis of sodium chloride (salt) brine. Nevertheless, the inorganic chemicals industry also represents one of the largest industrial purchasers of natural gas, ranking sixth among 4-digit industrial natural gas consumers.

5.3.2.1 Chlorine - Caustic Soda

The pulp and paper industry makes extensive use of both chlorine and caustic soda. Chlorine is used in the bleaching of paper, while the largest use of caustic soda is in converting wood fibre into pulp. Chlorine and caustic soda are produced jointly in chemically equivalent amounts by the electrolysis of brine. Three general types of electrolytic cells are employed for the production of chlorine and caustic soda: mercury cells, diaphragm cells and membrane cells. Figure 5.5 illustrates each of these electrolysis cells.

Figure 5.5
Chlorine Electrolysis Cells


Chlorine
Saturated brine
Anode (+)
Ions (Na⁺)
Depleted brine
Cathode (-)
Na–Hg Amalgam
Mercury in
Amalgam to decomposer
Chlorine
Hydrogen
Saturated brine
Sodium ions (Na⁺)
Chloride ions (Cl⁻)
Hydroxyl ions (OH⁻)
Anode
Brine
Cathode
Dilute caustic soda and sodium chloride
Chlorine
Hydrogen
Saturated brine
Water
Sodium ions (Na⁺)
Chloride ions (Cl⁻)
Depleted brine
Anode
Cathode
Concentrated caustic soda

a. **Mercury Cell**

b. **Asbestos Diaphragm**

c. **Perfluorosulfonic Acid Resin Membrane**

SOURCE: Kirk-Othmer, 1985, Vol. 26, Third Edition, p. 59.

The primary objective in each of the cells is the isolation of the separate reaction products, chlorine gas produced at the anode and sodium metal deposited at the cathode. After the completion of the chlorine extraction, the remaining dilute caustic solution is concentrated by evaporation, and the excess salts are removed and recycled. The strong caustic is then chemically treated to reduce the remaining water content, yielding the final caustic soda product.

5.3.2.2 Sodium Chlorate

The production of sodium chlorate is especially important to the pulp and paper industry, as it is mainly used as a precursor for the production of chlorine dioxide, a chemical used for bleaching wood pulp. Sodium chlorate manufacture is carried out by the same chemical process used to produce chlorine and caustic soda, the electrolysis of brine. However, the electrochemical cells used in the sodium chlorate process are notably different in that they are one compartment cells and thus do not possess diaphragms. In the production of caustic soda, the diaphragm is used to separate chlorine from hydrogen and caustic soda. When the diaphragm is removed, the chlorine and caustic soda react initially to form sodium hypochlorite, and in further reaction to form sodium chlorate.

5.3.2.3 Inorganic Acids

While the above inorganic chemicals illustrate the interdependence of chemical products with other manufacturing industries, the production of sulphuric acid and nitric acid reflect the interdependence that exists within the chemical industries. Sulphuric acid and nitric acid are both versatile inorganic chemicals used in many manufacturing industries, but the largest use of both these inorganic acids is in the production of fertilizer chemicals.

Sulphuric Acid

The largest use of sulphuric acid is in the production of phosphate fertilizers. Sulphuric acid is produced from a wide range of sulphur-based raw materials by a number of different processes. Which process is used largely depends on the raw material input. The principal sulphur-based raw materials used to produce sulphuric acid include sulphur recovered from sour natural gas, and waste gases produced during ore smelting. The sulphur recovered from sour natural gas is burned in brick-lined combustion chambers with dried air to produce sulphur dioxide. The sulphur dioxide is subsequently oxidized over a catalyst to produce sulphur trioxide, which is then reacted with water to yield sulphuric acid. Sulphuric acid can also be produced at nonferrous metal ore smelters from the sulphur dioxide waste gases that otherwise would be vented.

Nitric Acid

Nitric acid is predominantly used in the production of ammonium nitrate fertilizer chemicals. Nitric acid is produced by the ammonia oxidation process. While the operating details vary among plants, three basic steps are common in all ammonia oxidation processes: the oxidation of ammonia to nitric oxide, further oxidation of the nitric oxide to nitrogen dioxide and the absorption of nitrogen oxides in water to produce nitric acid.

5.3.3 Fertilizer Chemical Processes

Just as the production of ammonia is the backbone of the fertilizer industry, natural gas constitutes the heart of the ammonia process. In the manufacture of ammonia, natural gas is used both for feedstock and as a fuel for the primary reformer furnace, the single process heat application in the ammonia production process.

5.3.3.1 Ammonia

The manufacture of ammonia consists of four basic steps:

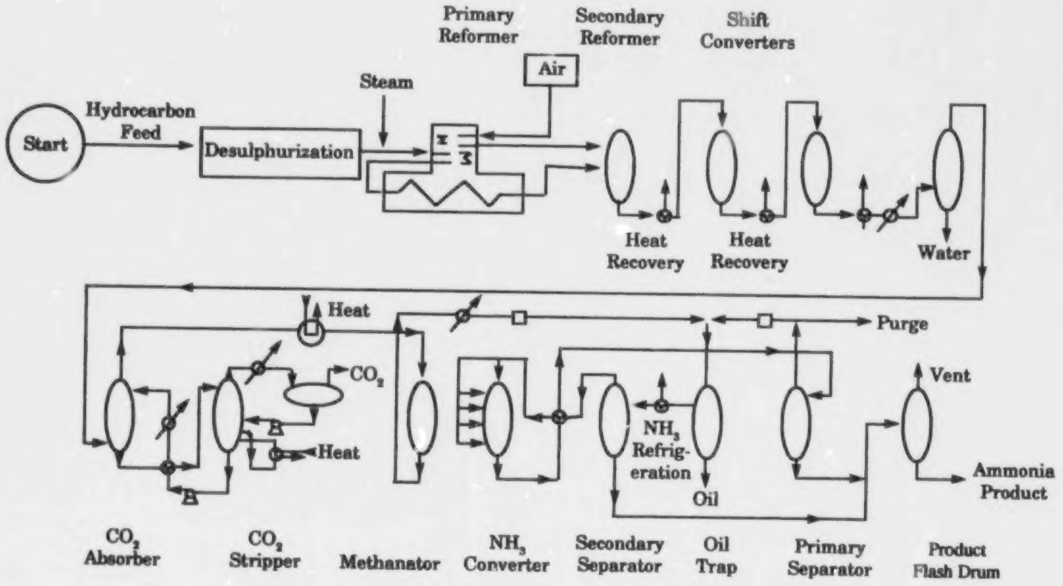
- synthesis gas preparation;
- carbon monoxide shifting;
- carbon dioxide removal; and
- ammonia synthesis.

Figure 5.6 illustrates a typical ammonia process.

Analogous to the initial processes involved in the production of methanol, the ammonia synthesis process begins with the desulphurization and subsequent steam reforming of the natural gas feed to yield synthesis gas. In ammonia production, the C-H ratio of the synthesis gas does not require the addition of CO_2, unlike the case for methanol synthesis. Rather, the CO in the synthesis gas is converted to CO_2 to recover more hydrogen for ammonia synthesis, and to remove the CO which poisons the ammonia catalyst.

Following the shift conversion of CO to CO_2, several processes involving solvents or aqueous solutions of potassium

Figure 5.6
Typical Ammonia Process


Start
Hydrocarbon Feed
Desulphurization
Steam
Primary Reformer
Air
Secondary Reformer
Shift Converters
Heat Recovery
Heat Recovery
Water
Heat
CO_2
Heat
Purge
Vent
NH_3 Refrig-eration
Oil
Ammonia Product
CO_2 Absorber
CO_2 Stripper
Methanator
NH_3 Converter
Secondary Separator
Oil Trap
Primary Separator
Product Flash Drum

SOURCE: Hydrocarbon Processing, November, 1969, p. 150.

carbonate are used for CO_2 removal. Residual amounts of CO and CO_2 are removed by methanation, a reaction of the synthesis gas with hydrogen over a nickel-based catalyst to yield methane and water. The final step involves the compression and conversion of the synthesis gas to ammonia. Ammonia is synthesized by reacting hydrogen and nitrogen in a ratio of 3 to 1 (by volume) in the presence of an iron oxide catalyst. Nitrogen is usually obtained by feeding air to the system, whereas sources of hydrogen may vary from plant to plant. For most plants the hydrogen feed is obtained from steam reforming of natural gas, while some plants receive hydrogen directly from petrochemical plants.

5.4 Energy Use in the Chemical Industries

The preceding process descriptions have revealed that energy use in the chemical industries is predominantly the use of natural gas and electricity. By outlining the energy flow through the chemical processes described in Section 5.3, and commenting on both changes in total energy efficiencies and the potential for technological change, this section will provide a more comprehensive discussion of energy use in the chemical industries. This does not include process feedstocks as energy use. The petroleum product requirements are therefore much lower than if feedstock volumes were included.

5.4.1 Energy Flows and End-Use

The pyrolysis heaters used in ethylene production, as well as the reforming furnaces used to produce methanol and ammonia, are very similar to the fired heaters and furnaces used in the petroleum refining industry. Consequently, the discussion on fuels use in refinery fired heaters given in Section 4.4.1 is equally applicable here. Particularly, the cracking reactions involved in ethane pyrolysis and the steam reforming of natural gas are analogous from an energy requirement standpoint to the cat cracking, reforming and hydrocracking processes in the refinery. More specifically, pyrolysis heaters and reforming furnaces also rely exclusively on the firing of gaseous fuels.

A salient difference exists, however, with respect to the composition of gaseous fuels burned by the chemical industries. Unlike refineries, where the largest portion of direct heat fuel consumption is met by burning by-product refinery fuel gas, most chemical industries must satisfy their direct heat fuel requirements by burning purchased natural gas. The one notable exception involves ethylene production, where the methane by-product produced during ethane pyrolysis is capable of satisfying virtually the entire direct heat fuel needs of the plant. Hydrogen is also a valuable by-product that can be used internally or sold.

In the petrochemical and ammonia processes, large amounts of steam are produced from quenching and boiler operations. In addition to being used for process heat, steam is used in powering turbines to generate electricity. This generation of electricity provides additional low- and medium-pressure steam which can be recovered and used to meet process requirements. The largest use of electricity in the chemical industries is in driving the electrolysis processes. Electric power is also used in standard machinery such as pumps, fans and air-conditioned heat exchangers.

Energy use in the chemical industries in 1981 and 1986 is illustrated in Table 5.5. The data on individual fuel use are expressed in terms of total energy content, as well as percentage shares of total energy consumed. The table does not include energy data for fertilizer chemicals, as 1985 represents the only year in which individual fuel specific data for the fertilizer industry is available. Table 5.6 contains this 1985 data for the fertilizer industry.

Tables 5.5 and 5.6 clearly demonstrate the overwhelming use of natural gas and electricity in chemicals manufacture. Over 90 percent of fuel consumption in the fertilizer industry is represented by natural gas and electricity, while these two energy forms constitute more than 75 percent of fuel use in all other chemical industries. Self-produced energy from process by-products also accounts for a notable share of energy use in the chemical industries, representing almost 15 percent of total energy use.

Again, similar to refinery heaters and furnaces, pyrolysis heaters and reforming furnaces are dual fired and can burn oil or natural gas. From Tables 5.5 and 5.6 it is evident that little residual or distillate fuel oil is burned. One reason for this might be that gaseous fuels, especially natural gas, provide a more even and controllable heat distribution, in addition to minimizing the risk of coking.

5.4.2 Changing Energy Efficiencies

The 1987 report from the CIPEC Chemical Industry Task Force revealed an overall improvement in energy efficiency of 39.6 percent over the 1972 base year. When compared with the new 1985

TABLE 5.5

ENERGY USE IN THE INDUSTRIAL CHEMICAL INDUSTRIES
1981 AND 1987

Fuel Type	Petajoules (1981)	Percent of Total Consumed (1981)	Petajoules (1987)	Percent of Total Consumed (1987)
Natural Gas	134.8	38.55	155.7	49.1
Electricity	118.9	34.00	101.6	32.0
Distillate Fuel Oil	2.2	0.62	3.8	1.2
Residual Fuel Oil	27.4	7.83	2.8	0.8
Diesel and Gasoline	1.8	0.51	0.2	0.1
Propane and LPG	7.0	2.00	3.1	1.0
Coal and Coke	1.1	0.31	1.7	0.6
Steam	13.5	3.85	7.0	2.2
By-Products[a]	43.1	12.33	41.3	13.0
Total[b]	349.8	100.0	317.1	100.0

SOURCE: Canadian Industry Program for Energy Conservation, 1981 and 1987 Reports (Ottawa: Energy, Mines and Resources, 1982 and 1987).

[a] Includes process by-products, vent gases, drips, slops, pitch, sulphur, hydrogen, waste oils, etc.
[b] Does not include feedstock volumes.

TABLE 5.6

ENERGY USE IN THE FERTILIZER INDUSTRY
1985

Fuel Type	Petajoules	Percent of Total Consumed
Natural Gas	56.6	71.4
Electricity	17.2	21.7
Distillate Fuel Oil	--	--
Residual Fuel Oil	0.5	0.6
Diesel and Gasoline	--	--
Coal and Coke	--	--
Steam	3.2	4.0
By-Products	1.8	2.3
Total	79.3[a]	100.0

SOURCE: Canadian Industry Program for Energy Conservation, 1975-1985: A Decade of Achievement (Ottawa: Energy, Mines and Resources, 1986).

[a] Does not include feedstock volumes.

base year, the energy efficiency gain in 1987 was 9.6 percent. The chemical industries, like petroleum refineries, include the use of waste fuels in their energy consumption figures. It is important to note that these efficiency gains are only attributable to those companies that report to CIPEC. While the participation of chemical companies in CIPEC is strong, it is considerably less than that of the other manufacturing industries included in this study, with only 75 percent of the total chemical industry represented.

The CIPEC Chemical Industry Task Force does not collect data on the fertilizer industry; rather, this is the task of the Canadian Fertilizer Institute (CFI). Since 1984 the CFI has published an annual report on the fertilizer industry based on statistical and financial information provided by member companies. However, the only energy consumption data reported is annual natural gas consumption. Total energy consumption and data for other individual fuels used are not available for years other than 1985, the one year in which the CFI reported such detailed information to CIPEC. As a result, it is difficult to make substantive comments regarding changing energy efficiencies in the fertilizer industry.

The peak investment year for general energy savings projects in the chemical industries was 1983. The nature of these investment projects was such that they required 2 years to implement and an additional year to observe the results. Thus, the energy efficiency gains in 1986 were partly due to previous investment in new machinery and equipment. As for sizeable increases in the rate of efficiency gains in the short term, the outlook remains cautious as annual expenditures on new machinery and equipment have declined each year since 1983, with the exception of 1986.

Referring to Table 5.5, two significant changes in energy consumption patterns in the chemical industries over the 1981 to 1987 period can be identified. First is the more than 10 percentage point increase in the natural gas share of total energy use. This increase came largely at the expense of a decrease in the use of residual fuel oil. Off-oil incentive programs in the early 1980s, coupled with deregulation and lower natural gas prices, are the main reasons behind this substitution. Lower oil prices in the mid-1980s abated this rate of substitution, as companies with dual firing capabilities benefitted from temporarily switching back to burning oil.

The other important trend in energy use in the chemical industries has been the decrease in purchased electricity. Increased use of cogeneration in chemical plants, along with the increasing substitution of waste fuels for purchased energy evidenced by the slight increase in the by-products share, has resulted in a 2 percentage point decrease in the purchased electricity share. Substitution away from purchased electricity has also been aided by the fact that permanent energy conservation improvements are easier to implement and require less maintenance in electrical systems than in thermal fuel systems.

5.4.3 Cogeneration

Because of the large amounts of steam and electricity that characterize the energy flow in chemical plants, the chemical industries--like the pulp and paper industry--represent a considerable theoretical potential for cogeneration. Indeed, in 1986, a number of chemical participants reported to CIPEC that the addition of new cogenerating equipment had provided very large gains in efficiency.[15]

While steam turbine systems currently represent the most prevalent form of cogeneration in Canada, the cogeneration system that is the most applicable to the chemical industries is the gas turbine system. The principal reason for this is that the gas turbine relies exclusively on the firing of hydrocarbon fuels, which already constitute a major portion of the chemical industries' energy profile. Other advantages of the gas turbine system include the fact that it requires less space than a steam turbine system and, more importantly, has a lower first cost than a steam turbine system of comparable capacity.[16]

As mentioned in Chapter 2, the gap between the amount of cogeneration that is technically feasible and the amount that is likely to be installed must be recognized. Gas turbine systems are becoming increasingly attractive in regions where natural gas is readily available and inexpensive. However, factors such as future energy prices, technological change and future regulatory policies are likely to have a considerable impact on the amount of cogeneration that is actually developed.

The conclusions from CERI's Study No. 24, Industrial Cogeneration in Canada: Prospects and Perspectives, regarding regional variations in cogeneration potential were also outlined in Section 2.4.3. The greatest potential for cogeneration among the western provinces exists in Alberta, with the majority of that potential residing in the petrochemical sector. At present, Ontario is home to the largest gas turbine cogeneration plant in Canada, Dow Chemical in

Sarnia, with 150 MW already installed. The Ontario Ministry of Energy estimates that 218 MW, or 16 percent, of the total cogeneration capacity likely to be implemented by the year 2000 is in the chemicals industry.[17]

5.4.4 Technological Change in Chemicals Manufacturing

As with the outlook for the petroleum refining industry, fundamental process changes are not on the short-term horizon for the chemical industries. Some new processes will be developed and brought on line, but only in very select chemical markets. Canadian chemical companies continue to produce a larger proportion of bulk commodities. The majority of emphasis regarding technological change is likely to be placed, therefore, on modernization programs to update existing equipment and on addressing environmental concerns.

The equipment changes will be dominated by the increased implementation of automated systems. Advanced computerized process control systems and optimization techniques represent the heart of this automation drive. Some chemical plants--like the Alberta Gas Ethylene plant--already possess such advanced process control technology. In addition, new computerized simulation software programs are also available for distillation equipment.

In regard to environmental concerns, a sizeable portion of chemical producers' budgets is devoted to research and development on sophisticated environmental protection devices. With each year bringing more severe regulations, an increasing obligation is placed on chemical companies to maintain and update these facilities. Environmental concerns that will demand increasing attention in the near term are waste-water treatment, stack emissions and advanced bleaching technologies to eliminate dioxin contamination.

In the fertilizer industry, the focus of technological change is also on the long term. While some ammonia plants constructed in the past 3 years, like the CIL plant in Sarnia, are 25 percent more efficient with respect to natural gas use than those built 10 years ago, the process changes that facilitated this large efficiency gain have been pushed to the limit, and little room remains for further large-scale improvements. In addition, lower fertilizer prices in recent years have diminished incentives to pursue even minor efficiency reductions. Fertilizer producers agree that further efficiency reductions are a necessity, but any significant gains in efficiency can only be realized in the long run.

One particular long-run technological change involves the manufacture of fertilizer chemicals from an energy producing, coal-conversion process: coal gasification. The synthesis gas required for ammonia and other synthetic chemicals can be produced from the gasification of coal, as opposed to from the steam reforming of natural gas.

In the gasification process, oxygen and steam are employed to convert dried coal into gas. The resulting crude gas is quenched to remove tar, oil and carbon dioxide. Synthetic gas produced from this process could not substitute for natural gas in high-grade uses, since it does not have the requisite heating value or composition. However, it can be employed in low-grade uses such as petrochemical and fertilizer feedstock. The commercial viability of coal gasification will remain limited as long as plentiful and competitively priced supplies of natural gas are available.

The most intensive efforts related to a major technological change in the fertilizer industry are being carried out by researchers in the seed industry. Some plants, such as soybeans and clover, are able to fix their own nitrogen, and therefore do not require nitrogen from fertilizers. Using bio-technology, researchers hope to isolate the genes responsible for this occurrence and then transfer them into major consumption crops, like wheat and corn, which currently require nitrogen from fertilizers. If this particular technology proves successful, i.e., the genes can not only be isolated and transferred, but are also effective once in place, then ammonia would no longer need to be added to the fertilizer cycle. However, there is little cause for alarm in the fertilizer industry as the viability of this technology on a large scale remains suspect, certainly for the next 20 to 25 years.

5.5 Conclusions

While no fundamental process changes are predicted for the chemical industries, continued efforts in process automation and control will lead to increased energy efficiency and environmental safety. Cogeneration represents the most promising potential for natural gas demand growth, but implementation will depend on the regional regulatory framework and electricity rates relative to natural gas prices. For the fertilizer industry, coal gasification represents a potential back-stop technology for feedstock supply. Its application depends on the availability and relative prices of coal and natural gas and the associated relative production costs. In summary, natural gas will experience competitive pressure from both electricity and coal, but should be capable of securing a long-term, large volume market.

Footnotes

[1] Canada, Statistics Canada, Chemical and Chemical Products Industries, Catalogue No. 46-250, Annual (Ottawa: Supply and Services Canada, February 1988), Table I.

[2] Ibid.

[3] The Canadian Chemical Producers' Association. The Canadian Inorganic Chemical Fact Book Update 1987: The Canadian Petrochemical Fact Book Update 1987; The Canadian Organic and Specialty Chemicals Fact Book Update 1987 (Ottawa: The Canadian Chemical Producers' Association, 1988).

[4] Statistics Canada, Chemical and Chemical Products Industries, p. 13.

[5] The Canadian Chemical Producers' Association, The Canadian Petrochemical Fact Book Update 1985.

[6] Oil and Gas Journal Data Book: 1985 Edition. (Tulsa: PennWell Publishing Company, 1986), p. 131.

[7] The Canadian Chemical Producers' Association, The Canadian Petrochemical Fact Book Update 1987.

[8] The Canadian Chemical Producers' Association, The Canadian Inorganic Chemical Fact Book Update 1987.

[9] The Canadian Chemical Producers' Association, The Canadian Chemical Industry Fact Book Update 1987.

[10] Statistics Canada, Chemical and Chemical Products Industries, p. 13.

[11] Canadian Fertilizer Institute, Annual Report 1985 (Ottawa: Canadian Fertilizer Institute, 1986).

[12] Texaco Canada Inc., Corporate Planning and Economics Department, Economics Division, Energy and Economic Data Book, 1987/88 (Calgary: Texaco Inc., 1988), pp. 225-226.

[13] Ibid., p. 224.

[14] Ibid., p. 226.

[15] Canadian Industry Program for Energy Conservation, 1986 Report (Ottawa: Energy, Mines and Resources, 1987).

[16] Acres International Ltd., Cogeneration Potential in Ontario and Barriers to its Developments, report prepared for the Ontario Ministry of Energy (Toronto: Ontario Ministry of Energy, February 1987).

[17] Ibid.

Chapter 6

INDUSTRY SCENARIOS

This chapter outlines the specific assumptions that underlie the reference case and two sensitivity scenarios run by the SERF model to generate industrial energy demand. These assumptions fall into two categories:

- growth in industrial output, and
- changing energy intensities of production.

The role of these assumptions within SERF is discussed in Section 6.1, while Sections 6.2 and 6.3 outline the forecast values of the input variables in detail. Section 6.4 presents assumptions for the two alternative scenarios, one involving no export growth for manufactured products, and one examining the effects of constant energy intensity of production. The results of the model runs are presented in Chapter 7.

6.1 The Role of Assumptions in SERF

As noted in Appendix C, SERF is a demand driven, input-output based model. Domestic product demands are calculated based on projected changes in the structure of and growth in population. The input-output structure of SERF allows the generation of industry growth rates that take into account all inter-industry product flows. Aside from assumptions regarding demographic developments and household and industry consumption structures, the main variables influencing secondary manufacturing growth is projected export growth for each industry. As seen in Chapters 2 through 5, the energy-intensive industries are also, with some exceptions, highly export oriented. Section 6.2 will outline the reference case export scenarios, reflecting projected export growth paths for each of the industries.

The role of the SERF model is one of providing an overall framework, ensuring internal consistency between industries, and incorporating the effect of structural changes in the population, while calculating the total demand for, and production of, manufacturing outputs. The demand for each of the energy forms is then derived from the projected energy intensities multiplied by the output from each industry. SERF does not have the capability to generate such end-use model results, predicting technological changes and conservation efforts within each industry.

While energy prices do not enter into the SERF model directly, assumptions regarding prices clearly affect the projected energy intensities. The relationship between energy prices and end-use of energy is analyzed in process models of individual industries. For the B.C. pulp and paper industry, energy prices were input into the ISTUM model,[1] providing projections for penetration of new production technologies and resulting energy intensities in that industry. No other end-use models were run specifically for this study, but detailed results with sensitivities from previous runs of MARKAL and MEDEQ were made available, and discussions regarding INDEPTH and AERAM parameters greatly aided the development of reasonable energy intensity assumptions. The structure and scope of these models are discussed in more detail in Appendix B.

In addition, documentation of extensive process models from the U.S. was considered.[2] These intensities reflect both the rate of conservation, or increase in total energy efficiency, and the nature and extent of substitution between different energy forms.

The forecasted energy prices and resulting intensities are included in Section 6.3 and constitute, along with the outlook for exports, the other set of input variables for the SERF scenarios created for this study. Forecasts are extended to the year 2015. Such a long-term framework is required in order to capture the potential effect of technologies that are still in the experimental stages, since capital turnover can take up to 30 years.

Domestic demand for industrial products depends on the size and characteristics of the Canadian population. The demographic scenario underlying this study assumes an aging population with lower fertility. The low fertility rate is only partially offset by a slight growth in net migration, so that the population size will actually start to decline at the end of our forecast period, reaching a high of 28.7 million people in 2015. The total number of households continues to grow until 2020 due to a steady fall in the number of persons per household.

The labour force starts to decline earlier, peaking at 16.7 million people in 2010, consistent with the overall aging of the population. The dependency ratio provides a measure of the portion of the population that must be supported. It is calculated by dividing the number of people between ages 0 and 15 and over 66 by the number of people aged 16 to 65. This dependency measure is slowly falling until around 2008 after which it gradually starts to increase. Compared to the historical period, the dependency ratio is still very low by the end of the forecast horizon. Both the dependency ratio and the percentage of the population in the labour force are shown in Figure 6.1.

6.2 Industry Export Projections

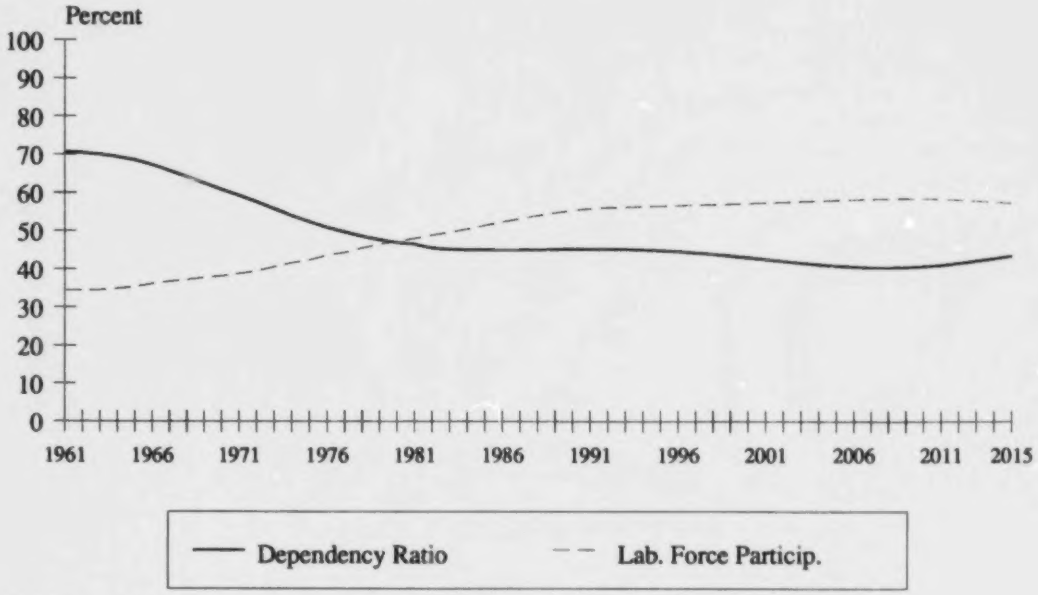
The penetration of Canadian commodities into foreign markets depends on factors largely outside of domestic control, such as foreign economic income and growth, interest and exchange rates, and foreign tariffs and quotas. The industries under analysis have a long history of supplying competitively priced commodities to export markets. As indicated in the industry descriptions, Canada has world-scale establishments in each of the four main industries examined.

Canadian industries are traditionally heavily resource oriented, producing primary products that are further refined into higher value added products closer to large markets, often outside the country. Thus, Canada exports large amounts of pulps and newsprint rather than coated specialty papers, ethylene rather than finished plastic products or specialty resins, and Canada also exports a large proportion of domestic heavy oil, while importing light, sweet crude for domestic refining. The degree of upgrading that takes place domestically tends to be limited by the distance to major markets and associated transportation costs, industrial organization and foreign ownership.

As indicated in the previous chapters, Canada's main export market is the U.S. There has been a fair amount of discussion in the last decade over the future role in world trade of third world countries, where primary industries are developing with considerable advantages in resource and labour costs. In particular, production from South American and Asian countries is seen as a threat to established Western producers of primary products. However, exports of such products from developing countries is limited by transportation costs, in particular if overland transportation is required, and increased domestic consumption in the developing nations themselves. There is also a trend towards developing countries increasing their volume share of output, while the OECD nations retain their share in terms of value added, indicating a simultaneous shift in OECD countries towards secondary, higher value production.

Figure 5.4

Figure 6.1
Labour Force Participation and Population Dependency Ratio



SOURCE: Socio-Economic Resource Framework, University of Waterloo, February 1989.

The SERF input-output tables treat each industry in considerable detail with respect to export of commodities, subdividing the industries' commodities into at least 8 categories, in the case of petroleum refineries, and up to 56 categories in the case of chemical manufacturing. For each industry it is, therefore, possible to incorporate the effect of changing composition of the final product or a higher degree of domestic refining of commodities, by adjusting the export product categories accordingly.

The export scenarios are based on "business as usual" or a "through-put" society, where consumption habits of households do not change radically. Overall growth in the resource-intensive industries is not substantial. They are assumed to maintain their present market shares abroad, or where specific effects of the Free Trade Agreement can be identified, the industries are assumed to grow or decline in accordance with relative productivity gaps and competitive advantages. Some additional growth is assumed for secondary production, indicating a slight increase in value-added manufacturing domestically. Beyond this, domestic processing of primary commodities is assumed to be limited by Canada's industrial structure. The U.S. market will remain the main destination for Canadian exports. Note that the growth rates are intended as indications of long-term trends and do not reflect short-term cyclical swings.

6.2.1 Exports of Pulp and Paper Products

Ten commodity categories of pulp and paper products are recognized in SERF. Newsprint is by far the largest, followed by pulp and other printing papers. There are two trends to be noted in the export growth rate projections. The first is the relative decrease in kraft pulp and kraft products, as CTMP and TMP processes replace some kraft pulping capacity and kraft products are subject to increased competition from plastics and other advanced materials. The second trend is based on the assumption of a higher degree of domestic upgrading and some specialization in fine paper and printing grades. The remaining categories (paper towels, tissue and wrapping paper and paper board), are assumed to maintain export shares and grow according to the domestic population growth rates. Table 6.1 summarizes the projected annual growth rates for pulp and paper exports, specifying the starting point of 1981 exports expressed in 1971 constant dollars. Figure 6.2 illustrates the total export and production growth for pulp and paper extending from the historical period through the forecast.

Figure 5.4

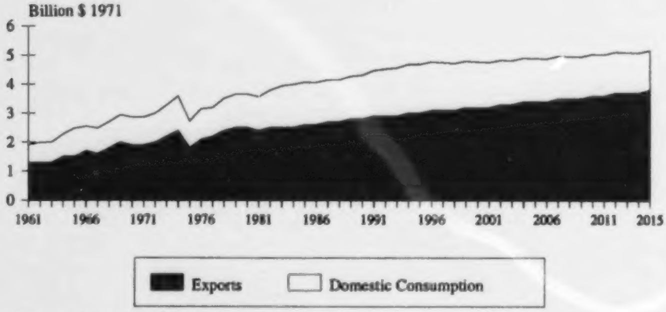
TABLE 6.1

PULP AND PAPER EXPORT SCENARIO

	Value of Exports ('000 $1971)	Annual Average Growth Rates (percentages)			
	1981	1981-1985	1986-1990	1991-2000	2001-2015
Pulp Chips	26,780	1.0	2.5	1.5	1.0
Pulp	974,414	1.0	2.5	1.5	1.0
Newsprint	1,179,454	1.0	2.7	1.5	1.0
Other Printing	119,071	2.0	3.5	3.0	2.5
Fine Paper	12,537	2.0	3.5	3.0	2.5
Tissue Paper	10,354	1.0	1.5	1.0	1.0
Wrapping Paper	45,474	1.0	1.5	1.0	1.0
Paper Board	62,213	1.0	1.5	1.0	1.0
Paper Towels	982	1.0	1.5	1.0	1.0
Vanillin	7,408	1.0	1.5	1.0	1.0
Total	2,438,687				

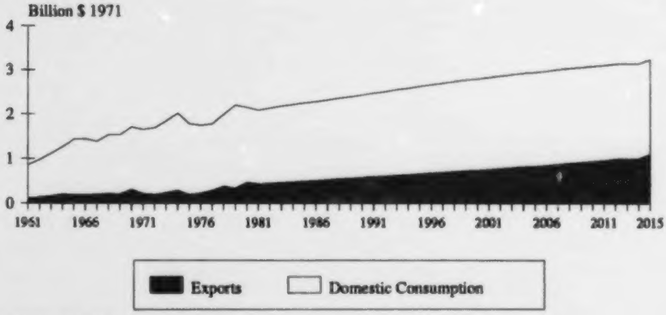
SOURCE: Socio-Economic Resource Framework, University of Waterloo, July 1988, for value of exports. Canadian Energy Research Institute for growth rates.

Figure 6.2
Total Production of Pulp and Paper



SOURCE. Socio-Economic Resource Framework, University of Waterloo, February 1989.

Figure 6.3
Total Production of Iron and Steel



SOURCE: Socio-Economic Resource Framework, University of Waterloo, February 1989.

Although the growth in newsprint exports reached a high rate of 2.7 percent per year in 1985 and 1986, this was partially a cyclical response to the economic recession of the early 1980s. Over the last decade specialty paper production has grown at more than twice the rate of newsprint production. This trend is predicted to continue as Canada has advantages both in wood and energy costs. Furthermore, Canada has a large number of older, smaller and less efficient paper machines. These can be retrofitted and converted to specialty paper production without massive capital outlays. U.S. capacity for fine paper production has not kept up with demand growth, and Canada is expected to continue to take advantage of this market niche.

Over the longer term, as noted in Chapter 2, paper machines are expected to continue to become increasingly flexible in large integrated plants, taking advantage of economies of scale while producing a range of high grade papers to customer specifications. The Canadian paper industry will have to continue its their efforts in research and capital investment to remain competitive in the long term.

Newsprint markets are seen as mature with a slightly smaller but still significant growth potential. As a standard commodity product, it is also more dependent on exchange rate and growth fluctuations, whereas specialty products can command a certain degree of customer loyalty. The Free Trade Agreement is not seen to have an appreciable, direct impact on the industry.

6.2.2 Exports of Iron and Steel

The iron and steel industry is also subdivided into ten product categories in SERF. The dominant products are steel rods and bars, followed by steel slabs, pig iron, carbonated steel and steel plates. Table 6.2 identifies the production categories, their value of exports in 1981 and the projected export growth rates. Figure 6.3 shows the total development in exports and production from the historical period through the end of the forecast period.

Compared to other primary industries, the outlook for Canada's iron and steel sector is quite optimistic. The industry has the advantages of "state-of-the-art" facilities. Whereas a number of foreign steel industries are either directly state-owned or dependent on government subsidies, the Canadian steel industry has privately managed to undertake major modernization through periods of erratic prices and economic downturns. The proximity to both domestic and

TABLE 6.2

IRON AND STEEL EXPORT SCENARIO

	Value of Exports ('000 $1971)	Annual Average Growth Rates (percentages)			
	1981	1981-1985	1986-1990	1991-2000	2001-2015
Ferro Alloys	24,718	3.6	3.5	3.5	3.5
Pig Iron	55,021	2.5	2.5	1.0	0.5
Steel Slabs	70,683	3.0	2.5	2.0	1.0
Steel Castings	4,615	4.0	4.0	3.0	3.0
Steel Rods and Bars	110,576	4.0	4.0	3.5	3.0
Steel Plates	35,770	3.6	3.5	3.0	3.0
Carbonated Steel	54,759	3.6	3.5	2.5	3.0
Tin Plate	30,345	3.0	3.5	2.5	2.5
Galvanized Steel	27,530	3.6	3.5	3.0	3.0
Rail Tracks	21,851	3.0	2.5	2.0	1.0
Total	435,868				

SOURCE: Socio-Economic Resource Framework, University of Waterloo, July 1988, for value of exports. Canadian Energy Research Institute for growth rates.

U.S. markets, domestic ore deposits and the availability of cheap energy are structural factors that contribute to the industry's long-term competitive advantage.

The industry is expected to continue pursuing market advantages through innovation, but further technological changes will occur slowly over time as profitable opportunities arise, since capital costs are substantial. For example, an aging coke battery may represent an opportunity for investment in some form of direct reduction process, reliant on non-coking coal.

Free trade is expected to provide a further boost to the industry. Increased access to the U.S. market will be advantageous given Canada's competitive position. Furthermore, the elimination of tariffs on imported machinery and equipment from the U.S. will lead to lower capital costs for domestic steel mills.[3]

The growth rates in Table 6.2 also exhibit a trend towards increased domestic refining. Exports of pig iron and semi-finished steel slabs will grow more slowly than exports of steel rods and plates, as more products are upgraded and finished domestically. Iron and steel castings, in particular, are expected to be under increasing competitive pressure from low-cost producers in newly industrialized countries and from alternative materials such as ceramics, aluminum and plastics.[4]

6.2.3 Exports of Petroleum Products

The traditional approach to petroleum product growth is to forecast uniform growth across all products, reflecting constant breakdown ratios of a barrel of crude oil into products. Considering the changing domestic crude oil supply characteristics towards heavier, lower quality crude and a simultaneous changing composition of demand towards lighter petroleum products, petroleum refineries are forced to exhibit increasing flexibility in their production processes. In the short term, this places increasing pressure on the industry's cat-cracking capacity and isomerization units.

In the longer-term perspective, increased investment in hydrocracking facilities and continued development of improved catalysts, such as the fluid catalytic cracking process, will enable the industry to respond to these pressures. The future complex and integrated refineries are likely to exhibit increasing product and process flexibility.

The question remains whether Canada's light-end capacity will actually exceed domestic requirements, allowing for increased light-end exports. It is suggested that additional heavy and synthetic oil upgrading facilities will come on-stream, but that domestic demand for light-end products will be strong, so that Canada will continue to export a substantial amount of heavy crude feedstock.[5]

The other pertinent question relates to domestic refiners' need for octane enhancement, in particular in relation to the lead phase-down legislation. This causes increasing demand for aromatics and alcohols used as additives for octane enhancement and may limit the export growth of these products from domestic refineries. Domestic demand for aromatics and naphtha depends to a large extent on the activity of Canada's petrochemical industry. As outlined in Section 6.2.4, relatively slow growth is expected from older oil-based chemical plants, while ethylene and derivative production and aromatic products are expected to perform well. Increased supplies of aromatics from ethylene production will be available under this scenario, allowing exports of aromatics to remain largely unchanged. Naphtha is also forecasted to be available for export throughout the period.

According to CERI's World Oil Market Model (WOMM), the global trend of increasing demand for light-end products is likely to continue. The reference case WOMM forecast yields an average annual growth of 1.6 percent in world demand for motor gasoline, compared to 0.5 percent for middle distillates and 0.4 percent for heavy fuel oil, through year 2000.[6]

The assumptions for petroleum product growth rates are outlined in Table 6.3 for the eight products identified in SERF. The net changes amount to continued growth in exports of crude feedstock, fuel oil, greases and lubricants, benzenes and naphtha, while motor gasoline and LPG grow only slightly until year 2000.[7] Beyond the turn of the century, however, domestic upgraders and the chemical industry respectively are expected to consume a larger share of the domestic heavy and synthetic feedstock and of the aromatics, decreasing export growth for these products. At the same time, a greater surplus of light-end products is likely to develop, increasing export growth in LPG, naphtha and motor gasoline.

In general, it remains true that export growth rates are more closely tied across petroleum products than in other industries. The overall growth is also slow, compared to the other industries examined. Figure 6.4 illustrates total export and production growth

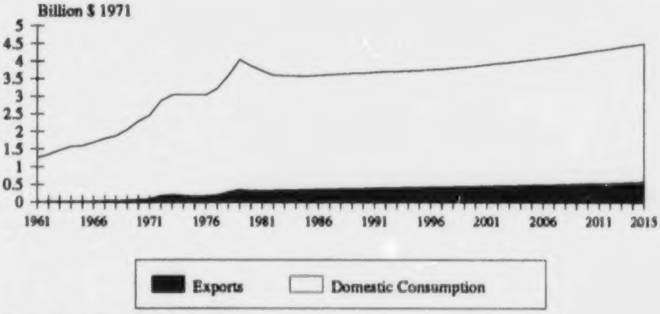
TABLE 6.3

PETROLEUM PRODUCTS EXPORT SCENARIO

	Value of Exports ('000 $1971)	Annual Average Growth Rates (percentages)			
	1981	1981-1985	1986-1990	1991-2000	2001-2015
Aviation Gasoline	1,488	1.0	1.0	1.0	1.0
Motor Gasoline	15,639	2.0	3.0	1.0	1.5
Fuel Oil	64,754	1.0	2.0	2.0	1.5
Lubricating Oil	2,210	1.0	2.0	2.0	0.0
Benzene	76,787	2.0	2.0	1.5	0.5
LPG	147,732	2.0	2.0	1.0	2.0
Naphtha	1,296	1.0	2.0	1.5	2.0
Feedstock	15,942	1.0	2.0	2.0	1.0
Total	325,848				

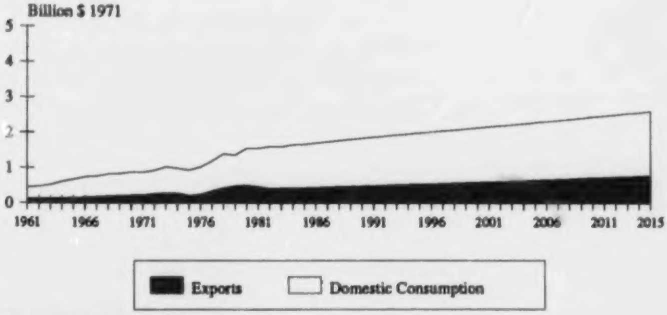
SOURCE: Socio-Economic Resource Framework, University of Waterloo, July 1988, for value of exports. Canadian Energy Research Institute for growth rates.

Figure 6.4
Total Production of Refined
Petroleum Products



SOURCE: Socio-Economic Resource
Framework, University of Waterloo,
February 1989.

Figure 6.5
Total Production of
Industrial Chemicals



SOURCE: Socio-Economic Resource
Framework, University of Waterloo,
February 1989.

for the petroleum refining industries in the forecast compared to the historical period.

6.2.4 Exports of Chemicals

Due to the diversity of the chemical sector, growth patterns will be discussed under the three main sub-categories established in Chapter 5: organic chemicals, dominated by petrochemicals; inorganic chemicals; and fertilizers. Figure 6.5 illustrates the aggregate historical and projected growth in production and exports of industrial chemicals, including organic and inorganic chemical industries. Figure 6.6 shows growth for agricultural chemicals, dominated by fertilizer manufacturing.

6.2.4.1 Exports of Petrochemicals

The large capacity expansions that took place in the 1970s and early 1980s were based on the premise of secure and low-priced domestic hydrocarbon supplies with rapidly rising international oil prices. This allowed a competitive advantage for the new world-scale facilities in Western Canada, in spite of capital costs up to 25 percent higher than for the U.S. Gulf Coast establishments. However, the Western Canadian plants are faced with freight disadvantages to reach major markets, and have to comply with restrictions in Alberta regarding location away from large centres. Furthermore, the falling crude oil and natural gas prices and deregulation of energy markets have gradually eroded the raw material cost advantage. The 1982-1983 economic recession contributed to industry losses in the 1980s. The industry has only now rebounded substantially and is again operating close to capacity.[8]

Settlement of contentious issues such as the Alberta ethane policy will contribute to the long-term stability and growth in Canada's petrochemical industry.[9] The Free Trade Agreement is perceived as advantageous for both methanol and ethylene production. The Alberta Energy Resources Conservation Board (ERCB) assumes in its low oil price scenario that additional capacity of 800 kilotonnes of ethylene is built in 1995 and 700 kilotonnes of methanol in 1998.[10]

The growth rates established in Table 6.4 reflect this optimistic outlook for the petrochemical industry. The natural gas and NGL-based ethylene facilities will grow and the older and smaller of the oil based facilities will gradually be modernized or replaced with new plants. A second trend reflected in Table 6.4 is the stronger

TABLE 6.4

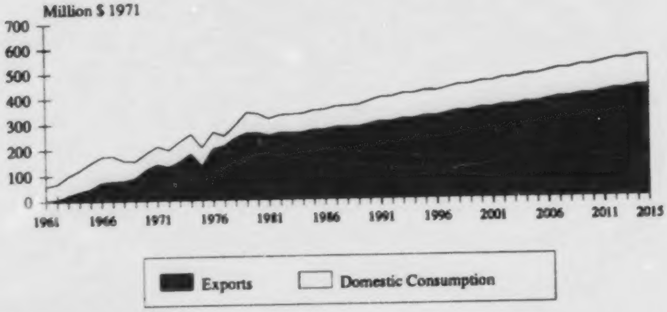
CHEMICAL EXPORT SCENARIO

	Value of Exports ('000 $1971)	Annual Average Growth Rates (percentage)			
	1981	1981-1985	1986-1990	1991-2000	2001-2015
Organic Chemicals					
Synthetic Rubber	35,282	1.0	3.0	2.0	2.0
Methyl Alcohol	18,017	2.0	3.0	2.5	2.0
Other Alcohol	11,610	2.0	3.0	2.5	2.0
Hydrocarbons	35,468	2.0	3.0	3.0	2.5
Styrene Monomers	42,386	1.0	3.0	3.0	2.5
Vinyl Chloride	7,140	1.0	3.0	3.0	2.5
Propylene and Isopropylene	3,859	1.0	3.0	3.0	2.5
Butylene and Isobutylene	3,622	1.0	3.0	3.0	2.5
Acetic Anhydrate	1,570	1.0	3.0	3.0	2.5
Phenol	542	1.0	3.0	1.0	1.0
Ether Acetate	26,170	1.5	3.0	1.5	1.0
Organic Acids	8,708	1.5	3.0	2.0	1.5
Other Organic Chemicals	46,416	1.0	3.0	1.0	1.0
Total	240,790				
Inorganic Chemicals					
Chlorine	5,072	1.0	2.5	2.0	2.0
Sulphuric Acid	1,234	1.0	1.0	2.0	2.0
Carbon Dioxide	461	3.5	3.5	3.0	3.0
Inorganic Acids	17,652	2.0	1.5	2.5	2.5
Caustic Soda	5,129	3.5	3.0	2.5	2.0
Sodium Chlorate	8,571	3.5	2.5	2.0	2.0
Sodium Phosphate	1,420	1.0	1.0	2.0	2.0
Metallic Salts	10,888	1.0	1.0	1.5	1.5
Phosphorous	24,436	1.0	1.0	2.0	2.0
Aqueous Ammonia	20,954	1.5	1.5	2.0	1.5
Fertilizer Chemicals	70,073	3.0	3.0	2.5	2.0
Titanium Dioxide	9,800	1.0	1.5	2.0	2.0
Other Inorganic Chemicals	47,685	1.0	1.0	1.5	1.5
Total	223,375				
Fertilizer					
Fertilizer	252,202	1.5	1.5	2.0	1.5

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, July 1988, for value of exports. Canadian Energy Research Institute for growth rates.

Figure 6.6

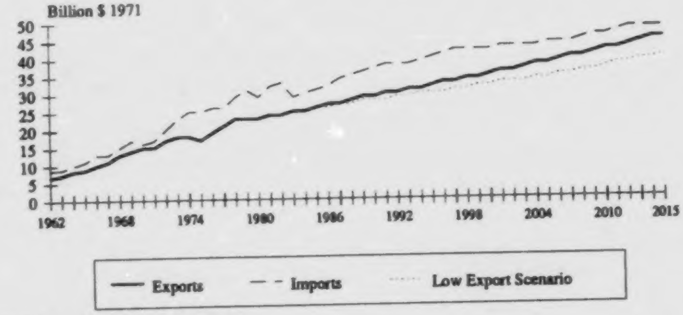
Total Production of Mixed Fertilizer



SOURCE: Socio-Economic Resource Framework, University of Waterloo, February 1989.

Figure 6.7

Total Canadian Exports and Imports



SOURCE: Socio-Economic Resource Framework, University of Waterloo, February 1989.

growth in secondary products such as propylene, butylene, acetic anhydrate, polyvinyl chloride and styrene monomers.

6.2.4.2 Exports of Inorganic Chemicals

Just as inexpensive hydrocarbon supplies provided the foundation for Canada's petrochemical industry, production of inorganic chemicals has been aided by a comparative advantage over trading partners in electricity costs. This advantage is expected to prevail over time.

As previously noted, the chemical producers depend on other manufacturing industries to sell their products. Technological change in chemical consuming industries, such as the increase in TMP and CTMP capacity to replace kraft pulping capacity in the pulp and paper industry, will affect the demand for chemical products.

New bleaching technologies are another example of such developments. Chlorine and chloride products are generally not expected to sustain growth, as alternative bleaching techniques in pulp and paper gain inroads. Caustic soda is also a product under pressure, as kraft pulping capacity stagnates and recycling technologies for pulping liquor become more efficient.

Among the inorganic acids, both sulphuric and nitric acid are closely tied to the fertilizer industry. Both are expected to recover gradually from the depressed markets of the late 1980s to undergo moderate growth in the 1990s. Table 6.4 details the assumptions regarding export growth rates for selected inorganic chemicals.

6.2.4.3 Exports of Fertilizers

Fertilizer demand is closely tied to the health of the agriculture industry, in particular to acreage planted and farm incomes. The world grain over-supply situation that characterized the 1980s has depressed the fertilizer industry as well. Although export volumes of fertilizers have increased, depressed prices have led to stagnant or falling values of export shipments.

The 1988 drought may constitute a turning point for the industry. As the decrease in supplies led to a depletion of grain inventories, the short-run market outlook has improved greatly.[11] However, for long-term growth to persist, fundamental problems of North American farm debt and world trade barriers and subsidies must be resolved. Figure 6.6 expresses this outlook of slow long-term growth in exports.

6.2.5 Other Exports, Total Imports and the Trade Balance

Exports for other manufacturing products in the fabrication and assembly component of SERF are predicted to grow at an average annual rate of 1.5 percent between 1981 and 1985, 2.5 percent till 1990, and 2 percent thereafter. The total historical and scenario exports for the economy are depicted in Figure 6.7. The predicted export and import growth rates are considerably lower than the historical period, particularly compared to the growth exhibited in the 1960s. The figure also shows that the historical trade balance deficit extends through the forecast, but diminishes slightly over time.

6.3 Reference Case Energy Intensity Forecasts

As new production technologies become commercially viable and efficiency measures are implemented, either through capital turnover or retrofits to existing equipment, the end-use demand for each energy form will change. The SERF model contains matrices of energy intensities, defined as constant dollar input of energy per constant dollar final product produced, for up to six energy carriers: motor gasoline, fuel oil and diesel, liquid petroleum gases, electricity, coal and natural gas, for each of the industries examined. These coefficients are measured in constant 1971 dollars as a proxy for physical data on energy content per unit output. Such physical data were not available in consistent time series across all industries. In order to obtain more meaningful intensity measures, the parameters are converted by multiplying with the 1981 average prices per joule for each fuel in each industry, generating coefficients in megajoules per 1971 dollar output.

The term energy intensity as used in this study reflects the purchased energy per dollar output, as opposed to input of a heat value in a specific end-use process. The energy intensities for an industry can be affected by changes in the efficiency of production processes, through conservation, adoption of new processes, response to stricter environmental standards, increased product refining and other structural changes in the industry. Since these intensities are measured at the plant gate as opposed to final end-use of energy, increased on-site generation of electricity using natural gas at the expense of purchased electricity would appear as increased natural gas intensity and decreased electricity intensity for the industry. For the purpose of analyzing final natural gas demand, this is the most useful approach.

These intensity coefficients must be projected for the entire forecast period. The various Canadian end-use and process models described in Appendix B have been reviewed and provided valuable input.

Since the process or end-use models require specific energy price forecasts to provide outlooks for energy intensities of production, sensitivity cases were sought that used input prices compatible with CERI's World Oil Market Model's Reference Price Scenario. This scenario and a High Resource sensitivity case leading to lower world oil prices, provided the basic reference price path and sensitivity for energy prices. These price scenarios are shown in Figure 6.8.

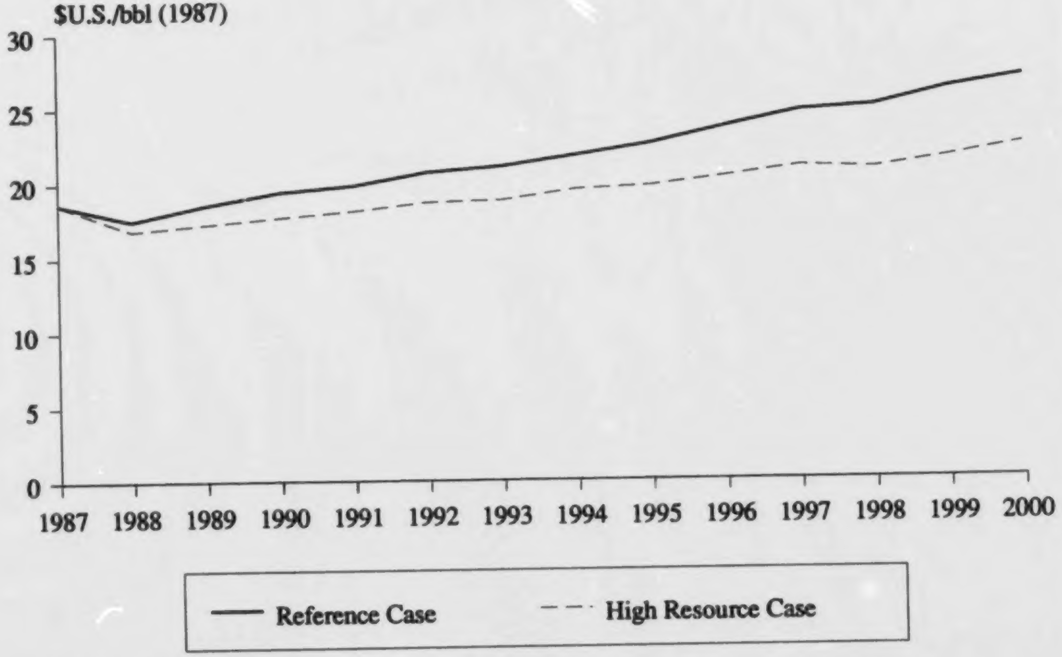
Perhaps the most comprehensive evaluation of industrial energy use to date was undertaken by Stanford University's Energy Modeling Forum.[12] The Forum ran a host of different models of industrial energy use, ranging from econometric and input-output to end-use and process models. Since the model runs were based on a common set of assumptions, notably the same energy price forecasts, the comparisons of final results threw light on current trends in energy use and the likely effects of penetration of new technologies. The relevance of those U.S. trends for Canadian manufacturing industries was assessed, and the U.S. process models provided valuable input into forecasting energy intensities for the Canadian industries considered in this study

Additional insight into likely energy efficiency and conservation measures was gained from the CIPEC task force reports. Results from a SERF run previously carried out to assess the impact of new electro-technologies, have also been examined.

6.3.1 Energy Intensity in Pulp and Paper Production

The pulp and paper industry has been quite successful in implementing energy efficiency measures, for example, through increasing use of waste fuels, and waste heat recovery systems. These changes have been implemented through housekeeping, energy equipment retrofits and installation of new energy equipment. The past trend of more than 2 percent average annual improvements in energy efficiencies cannot be expected to continue unabated.[13] There are several conflicting forces acting on end-use energy demand, and many of the one-time improvements in efficiency have been implemented. However, conservation opportunities remain, for example in high

Figure 6.8
World Oil Price Scenarios



SOURCE: CERI World Oil Market, Model, 1988.

efficiency boilers and burners, waste heat (especially steam) recovery and upgrading, increased use of hog fuels and cogeneration displacing purchased and other self-generated electricity.

The other commonly discussed trend is the increased electricity intensity or electrification of production processes. Although more than 85 percent of the increase in electricity use for the pulp and paper industry can be attributed to Hydro Quebec's industrial boiler program,[14] there are other process changes underway that favour increased electricity use. Increasing emphasis on the environment may advance the implementation of some of the chemical recovery technologies discussed in Chapter 2. Plasma gasification, mechanical vapour recompression and membrane separation processes all require increased electricity consumption. In addition, medium- and high-consistency pulping technologies increase electricity use due to increased pumping needs through bleaching, washing, screening and storage systems. Developments toward more TMP and CTMP capacity and a higher proportion of value added products will also lead to greater electricity intensity of production. In the dryer section, natural gas and electrical infrared drying technology will compete, potentially replacing steam drum drying, especially in high quality, specialty paper production. For the heavier product grades, impulse drying will likely begin to penetrate.

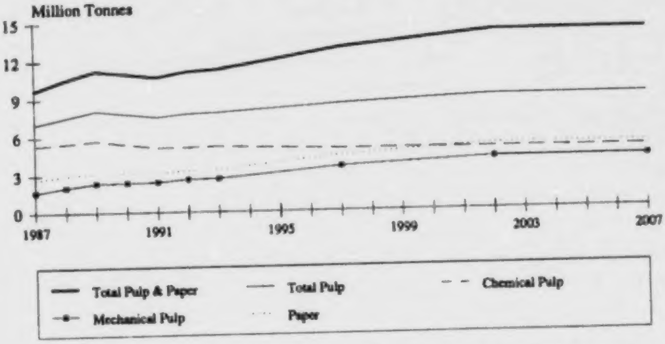
Between increasing use of waste fuels, conservation and recovery of process heat and new electrical processes, natural gas consumption appears to be under strong pressure in the pulp and paper industry. A crucial question therefore becomes to what extent higher electricity end-use demand will be satisfied through increased implementation of natural gas-based cogeneration facilities.

The ISTUM model (see Appendix B) was run specifically for this study. This process model of the B.C. pulp and paper industry provided an opportunity to test the price sensitivity of energy forecasts, the scope for conservation of energy forms and the effect of new production technologies for this industry.

As seen in Figure 6.9, the production path specified for ISTUM reflected a strong shift from kraft pulping towards TMP and CTMP capacity. Kraft production decreases slowly after the 1989 peak, while TMP and CTMP capacity expands until year 2002, increasing production of mechanical pulps by 28 percent over the entire period, or almost 2 percent per year until 2002. Paper production is growing even faster, reflecting increased upgrading. In fact,

Figure 6.9

B.C. Pulp and Paper Production[a]

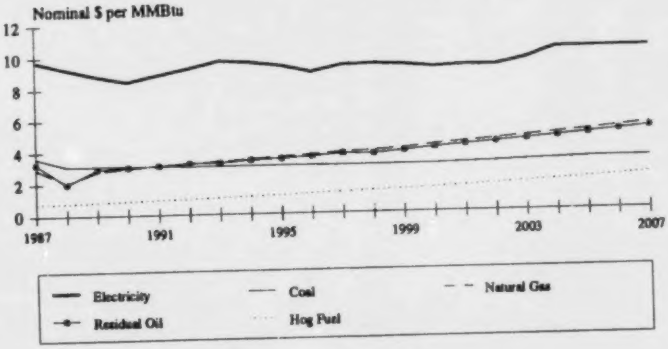


SOURCE: Industrial Sector Technology Use Model, Natural Resources, Management Program, Simon Fraser Univ., Dec. 1988.

[a]Total production, including used at mill.

Figure 6.10

British Columbia Energy Price Forecast



SOURCE: Inter-Fuel Substitution Demand Model, Department of Energy, Mines and Resources Canada, November 1988.

production almost doubles over the forecast period with the strongest growth taking place prior to 2002. The overall growth rate for total pulp and paper production is 3 percent per year until year 2000.

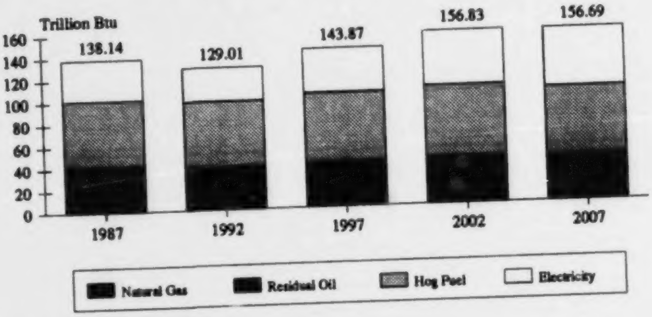
This production scenario, together with the two sets of energy prices, form the basis for the ISTUM runs performed for this study. The oil price path from CERI's World Oil Market Model shown in Figure 6.8 was run through the pricing component of the Department of Energy Mines and Resources' Inter-Fuel Substitution Demand Model (IFSD).[15] This model generates consistent regional price forecasts for all energy fuels based on a world oil price path, and for electricity prices based on projected capacity requirements and regional rate bases. The resulting B.C. industrial sector price scenarios are shown in Figure 6.10.

The energy demand results from the ISTUM runs are presented in Figure 6.11. Natural gas used in pulp production is expected to fall throughout the period as a result of conservation efforts, more efficient kraft production processes and the increased proportion of mechanical pulping over kraft pulping. For paper production, on the other hand, natural gas use will increase throughout the forecast period. The resulting total natural gas demand is shown in Figure 6.11 as decreasing for the initial period when the effect of conservation measurers is strong, increasing at a slow rate until year 2002, as paper production increases and CTMP and TMP pulping penetrates, and falling off slightly in the last period.

On-site generation of electricity is seen to increase, but at a fairly slow rate. This is exogenously constrained in the model to encompass only planned capacity. Net purchased electricity is initially decreasing as conservation measures are implemented, but continues to increase steadily throughout the period. Since the on-site generation results have not been optimized by the model for these runs, the results are insensitive to price changes. It is therefore concluded that natural gas potential could be substantially greater if the various forms of on-site electricity generation were pursued.

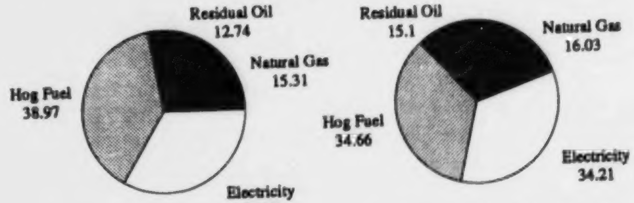
The other political constraint on the ISTUM results is the dedication of Vancouver Island pulp mills to natural gas use after the natural gas pipeline is assumed to come on-stream during the 1992-1997 period. This is a special circumstance that makes it harder to draw parallels from these results to the total Canadian pulp and paper industry.

Figure 6.11
Energy Demand for the B.C. Pulp and Paper Industry - Base Case



SOURCE: Industrial Sector Technology Use Model, Natural Resources Management Program, Simon Fraser Univ., Dec. 1988.

Figure 6.12
B.C. Pulp and Paper Industry
Relative Energy Market Shares in 2007



Reference Price Case
Total: 138.14 Trillion Btu

Low World Oil Price Case
Total: 156.69 Trillion Btu

SOURCE: Industrial Sector Technology Use Model, Natural Resources Management Program, Simon Fraser Univ., Dec. 1988.

The ISTUM results for residual fuel oil and hog fuel use indicate growth for both fuels after 1992, following implementation of initial conservation measures.

The important effect of lower prices for thermal fuels is evident from the low-price sensitivity case. Natural gas use increases both in pulp and paper production, yielding a larger net increase in natural gas use, relative to the reference case. For year 2007, total natural gas use is 11 percent above the base case results. The low price case also indicates substantial growth potential for residual oil at the expense of increased utilization of hog fuels. This sensitivity to lower prices is illustrated in Figure 6.12.

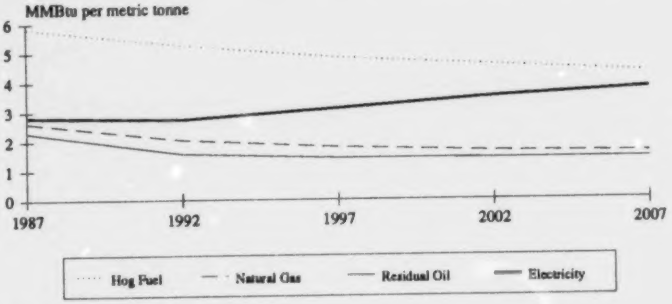
By taking the ratio between total purchased fuels and total production, an energy intensity measure for each energy form is obtained. These measures are illustrated in Figure 6.13 for the reference case results. Since these ISTUM outputs are region specific and in physical units (MMBtu per metric tonne), the intensity measures cannot be applied directly as SERF assumptions. Rather, the trends and rates of growth of these intensities give indications of reasonable adjustments to the energy input per dollar product output parameters of the SERF model. As Figure 6.13 indicates, natural gas intensity is predicted to fall steadily, the residual oil intensity falls sharply at first, then remains constant, and the hog fuel intensity is also falling. Electricity intensities are seen to rise quite substantially over the forecast horizon.

Table 6.5 and Figure 6.14 outline the projected growth rates for the pulp and paper SERF energy intensity coefficients, forming the basis for the reference scenario. Taking into account the potential for cogeneration, natural gas intensities are predicted to decline slowly over the forecast period, while the purchased electricity intensity increases, but again at a slower rate than indicated by ISTUM. The fuel oil intensity falls rapidly at first and then at a slower rate.

6.3.2 Energy Intensity in Iron and Steel Production

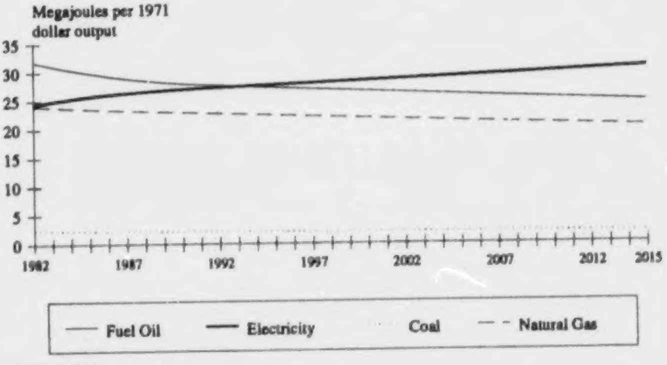
Over-capacity, capacity rationalization and upgrading projects, and variable scrap availability have contributed to slow and sometimes erratic energy efficiency improvements in the iron and steel sector.[16] However, the favourable economic outlook for this industry should permit substantial efficiency improvements over the long run,

Figure 6.13
Energy Intensities of B.C.'s
Pulp and Paper Industry - ISTUM Results



SOURCE: Industrial Sector Technology
Use Model, Natural Resources Management
Program, Simon Fraser Univ., Dec. 1988.

Figure 6.14
Energy Intensity Assumptions for
Canada's Pulp and Paper Industry



SOURCE: CERI.

TABLE 6.5

ENERGY INTENSITY OF PULP AND PAPER PRODUCTION

	Energy Intensity Coefficient[a] (megajoules per dollar)	Annual Average Growth Rates[b] (percentages)			
	1982	1981-1985	1986-1990	1991-2000	2001-2015
Fuel Oil, Diesel	31.814	(2.2)	(1.3)	(0.5)	(0.5)
Electricity	24.422	2.0	0.95	0.5	0.5
Coal	2.444	(2.1)	(0.9)	(0.5)	(0.5)
Natural Gas	24.127	(0.85)	(0.5)	(0.5)	(0.5)

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989 for 1982 energy intensities. Canadian Energy Research Institute for growth projections.

[a] Measured as megajoules per 1971 dollar value of output produced in 1982.
[b] Numbers in brackets represent negative growth rates, or decreased energy intensities.

through continued penetration of high efficiency furnaces and burners, and increased recovery and upgrading of waste heat.

In addition, the iron and steel industry is faced with the challenge of major process changes such as direct reduction, direct smelting, direct rolling and thin steel casting. These new technologies may lead to fundamental changes in the end-use patterns for energy.

As the proportion of pig iron produced in blast furnaces decreases, the coking rate is expected to continue declining. Other hydrocarbons, such as non-coking coal, oil and natural gas, will provide a source of carbon both for direct reduction, direct smelting and for hydrocarbon injection in conventional blast furnaces.

The proliferation of mini-mills with electric-arc steel melting is not in itself a threat to natural gas end-use markets, as natural gas intensity is actually greater in the mini-mill process. Furthermore, the possibility of implementing highly efficient, hybrid electricity-natural gas technologies for scrap melting represents a promising development for natural gas.

Improved automation and integration of processes will certainly increase the total use of electricity. On the other hand, substantial savings are possible, for example through use of high power electrical furnaces, high-efficiency motors and electric load management. Special electro-technologies, such as plasma and vacuum furnaces, are only expected to penetrate for production of high-value, specialty products, and only through capacity additions rather than replacements.

Continuous casting, hot charging, direct rolling and thin steel casting represent the greatest challenges to traditional natural gas end-use markets. These integrated processes change reheat requirements to maintaining, supplementing and equalizing heat, rather than heating a workpiece from ambient temperatures. As reheat and heat treating traditionally consume more than half the natural gas used by an integrated iron and steel producer, natural gas volumes are clearly threatened by a shrinking reheat market.

Off-setting this is the decreased availability of coke oven and blast furnace gas, increasing the potential applications of natural gas. As the nature of reheat requirements change, the competition between natural gas and electricity will intensify in the remaining reheat market.

The crucial question again becomes to what extent natural gas will be used for generation of electricity. Cogeneration has not demonstrated the same economic potential in iron and steel as in the pulp and paper industry, but self-generation may be an attractive option for many producers. For example, natural gas-fired generators can be built to withstand the electric transients associated with firing electric-arc furnaces.

The growth rates for energy intensities in iron and steel production are outlined in Table 6.6. It is assumed that the natural gas intensity will be in steady decline as a result of conservation of process heat and a shrinking reheat market. Electricity use declines at a slow rate after 1990, reflecting a balance between the opposing trends of, on the one hand, increased automation, growth in electric steelmaking, and penetration of new electro-technologies; and, on the other hand, increased efficiency and co- or self-generation. Note that metallurgical coal is treated as a feedstock and not included in the coal intensity parameter.

6.3.3 Energy Intensity in Petroleum Refining

The petroleum refining industry has exhibited steady improvements in energy efficiency, exceeding in 1987 the CIPEC goal of a 30 percent improvement by 1990. However, the fall in energy intensity reflecting actual fuel use, without the CIPEC adjustments made for increased process severity and tighter sulphur emissions specifications, is actually less than half of the total reported improvement.[17]

It is assumed that energy efficiency measures will continue to be implemented, while heavier crude feedstocks and increased demand for light-end products will tend to increase the energy intensity of production. The net effect of these opposing trends is assumed to be a slow but steady decrease in the overall energy intensity of production. Efficiency improvements are accomplished by measures ranging from simple housekeeping, and improved heat recovery through reduced stack and radiation losses, to penetration of high efficiency burners and furnaces and advanced computer systems to control inter- and intra-process flows. Efficiency improvements are generally concentrated in process heat conservation, reducing thermal fuel use.

The development towards more complex and highly integrated refineries also enhances availability of refinery gas and the possibilities for recovering and using this gas efficiently. Since there

TABLE 6.6

ENERGY INTENSITY OF IRON AND STEEL PRODUCTION

	Energy Intensity Coefficient[a] (megajoules per dollar)	Annual Average Growth Rates[b] (percentages)			
	1982	1981-1985	1986-1990	1991-2000	2001-2015
Fuel Oil, Diesel	9.218	(2.2)	(0.9)	(0.5)	(0.0)
Electricity	14.420	(0.35)	0.0	(0.2)	(0.5)
Coal	0.055	(1.0)	(1.1)	(1.3)	(1.0)
Natural Gas	29.255	(0.85)	(0.6)	(1.2)	(1.5)

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989 for 1982 energy intensities. Canadian Energy Research Institute for growth projections.

[a] Measured as megajoules per 1971 dollar value of output produced in 1982.
[b] Numbers in brackets represent negative growth rates, or decreased energy intensities.

are efficiency advantages to staying on an all-gas system, fuel oil intensity is expected to decline at a faster rate than the natural gas intensity. Note that crude oil feedstock is not considered an energy form and therefore not included in the intensity parameters in Table 6.7.

Conservation opportunities exist for electricity as well, and for the initial time period the electricity intensity is expected to decline. However, more complex refineries will lead to increased motor drive and pumping needs, increased hydrogen production as investment in hydrocrackers takes place to fulfill octane requirements, and greater oxygen requirements for regeneration of catalysts. These are examples of trends that will tend to cancel out electricity efficiency gains. The intensity coefficient for electricity is therefore projected to remain constant after 1990. Table 6.7 outlines the complete scenario assumptions for energy intensities in petroleum refining.

6.3.4 Energy Intensity in Chemicals Production

General predictions are very hard to make for an industry as diverse as the chemicals and chemical products sector. Implementation of efficiency measures is expected to continue.[18] Continued improvements in housekeeping, process control, process balancing, waste heat recovery and upgrading will contribute to efficiency gains.

New electrical technologies are not predicted to have a major impact, at least not in the short run. For example, electric plasma arc technology is not likely to be implemented on a large scale over the forecast horizon. While advanced electrical membrane technologies have greater potential for higher value added, derivative products, these technologies are not projected to penetrate significantly into the production of bulk products.

The industrial chemical producers have a significant potential for cogeneration which, together with efficiency improvements in electricity use, is expected to more than cancel out any electrification trend. The electricity intensity coefficients, as shown in Table 6.8, are assumed after an initial slight increase to fall throughout the forecast period. The natural gas intensity is also assumed to decline, but at a slower rate than the oil intensity until year 2000, as natural gas will be used to cogenerate electricity.

For the fertilizer industry, the fuel oil intensity is assumed to decline steadily. Both natural gas and electricity intensities fall

TABLE 6.7

ENERGY INTENSITY OF PETROLEUM REFINERIES

	Energy Intensity Coefficient[a] (megajoules per dollar)	Annual Average Growth Rates[b] (percentages)			
	1982	1981-1985	1986-1990	1991-2000	2001-2015
Fuel Oil, Diesel	0.024	(2.0)	(1.7)	(0.8)	(0.5)
Electricity	4.238	(1.0)	(0.8)	0.0	0.0
Natural Gas	14.849	(1.0)	(0.9)	(0.5)	(0.5)

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989 for 1982 energy intensities. Canadian Energy Research Institute for growth projections.

[a] Measured as megajoules per 1971 dollar value of output produced in 1982.
[b] Numbers in brackets represent negative growth rates, or decreased energy intensities.

TABLE 6.8

ENERGY INTENSITY OF CHEMICALS PRODUCTION

	Energy Intensity Coefficient[a] (megajoules per dollar)	Annual Average Growth Rates[b] (percentages)			
	1982	1981-1985	1986-1990	1991-2000	2001-2015
Mixed Fertilizer					
Fuel Oil, Diesel	0.138	(1.0)	(1.0)	(1.0)	(1.0)
Electricity	1.104	(1.35)	(0.9)	(0.5)	(0.5)
Natural Gas	0.453	(1.35)	(0.9)	(0.5)	(0.5)
Industrial Chemicals					
Fuel Oil, Diesel	13.798	(0.5)	(0.4)	(0.0)	(0.0)
Electricity	24.452	0.35	(0.1)	(0.5)	(0.5)
Natural Gas	83.868	0.0	(0.1)	(0.9)	(1.0)

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989 for 1982 energy intensities. Canadian Energy Research Institute for growth projections.

[a] Measured as megajoules per 1971 dollar value of output produced in 1982.
[b] Numbers in brackets represent negative growth rates, or decreased energy intensities.

more rapidly to 1990, and then decline at an average 0.5 percent per year.

6.3.5 Energy Intensities of Other Manufacturing Processes

Among the remaining manufacturing industries, two were singled out in the energy intensity forecasts: cement production (SIC 355) and aluminum smelting and refining (SIC 295).

6.3.5.1 Energy Intensity in Cement Production

Cement production represents a highly flexible manufacturing process in terms of energy use. Producers can generally switch quickly between a variety of fuels, provided that investments in expensive fuel handling systems are not required. Thermal energy is used as kiln fuel, and these kilns have undergone important technological developments in the past, evolving from the long, wet process to the dry process which now represents 83 percent of Canadian cement capacity.[19] This change has been a source of substantial energy savings, as heat is only required for the chemical reactions involved in calcination and clinkering, not for evaporating the water content of the slurry, as in the wet process.

Future developments include the additions of preheaters and precalciners and the adoption of more efficient kiln structures such as rotary kilns. Efficiency gains from these changes will gradually penetrate over the next 10 to 20 years. Fluidized bed reactors are perceived to have limited economic potential in the forecast period.[20]

The flexibility in choice of fuel sources for cement production means that conventional thermal fuels such as natural gas must compete with coal, pitch, wood pellets and even municipal waste, subject to environmental approval for burning such alternatives. Mechanical energy is used mainly for grinding clinker to cement.

Table 6.9 outlines the assumptions regarding future energy intensities for cement production. Substitution away from oil products slowed considerably after 1986 due to lower world oil prices. Natural gas use increased in 1987 as deregulation and surplus volumes brought prices down to levels competitive with coal.[21] On average over the 1986 to 1990 period, natural gas intensity is assumed to continue declining, although at a slower rate than earlier. After 1990 process

TABLE 6.9

ENERGY INTENSITY OF CEMENT PRODUCTION

	Energy Intensity Coefficient[a] (megajoules per dollar)	Annual Average Growth Rates[b] (percentages)			
	1982	1981-1985	1986-1990	1991-2000	2001-2015
Fuel Oil, Diesel	26.330	(1.35)	(0.8)	0.0	0.0
Electricity	16.763	0.35	(0.1)	(0.5)	(0.5)
Coal	46.755	2.55	1.1	(0.6)	(1.0)
Natural Gas	70.580	(1.55)	(0.7)	(0.7)	(0.5)

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989 for 1982 energy intensities. Canadian Energy Research Institute for growth projections.

[a] Measured as megajoules per 1971 dollar value of output produced in 1982.
[b] Numbers in brackets represent negative growth rates, or decreased energy intensities.

changes are predicted to provide for steady declines in energy intensities for all energy forms.

6.3.5.2 Energy Intensity in Aluminum Production

Aluminum smelting and refining is the second largest subgroup of the primary metals industries, following primary steel production. The industry is a major electricity consumer. Reduction of bauxite to alumina has been carried out using the same basic (Bayer) process for almost a century, and only minor efficiency modifications may be expected for this process on the future. However, for the reduction of alumina to aluminum, continual improvements in electrode materials and more heat- and power-efficient electrolysis cells will contribute to increased efficiency. Two technological innovations show particular promise: the chloride electrolyte and reduction process, and developments towards direct smelting of aluminum using non-bauxite materials.

Table 6.10 outlines the energy intensity assumptions for the aluminum industry. Among the thermal fuels, the trend in the 1980s to substitute initially coal and then natural gas for fuel oil is halted, keeping oil intensity of production constant after 1990. A large proportion, close to 50 percent, of what SERF categories as fuel oil, is actually petroleum coke and pitch used as materials for catalysts. These applications can not be expected to undergo substantial efficiency changes.

This forecast predicts continued conservation of coal and natural gas use in thermal applications, which are mainly steam generation process. The largest potential energy savings lie in electricity consumption, with electricity intensity predicted to decrease by 1 percent per year after 1990.

6.3.5.3 Other Manufacturing Industries

For all of the remaining manufacturing industries located in the Fabrication and Assembly Component of SERF, Table 6.11 outlines the assumed growth rates for energy intensities. Substitution away from fuel oil slows down, leaving the fuel oil intensity constant after year 2000. Natural gas conservation efforts are stepped up, fielding 1 percent annual average declines in natural gas intensity after 2000. The initial increase in purchased electricity intensity is reversed after 1990. The electricity intensity is then assumed to decline at 0.5 percent per year till the end of the forecast period.

TABLE 6.10

ENERGY INTENSITY OF ALUMINUM SMELTING

	Energy Intensity Coefficient[a] (megajoules per dollar)	Annual Average Growth Rates[b] (percentages)			
	1982	1981-1985	1986-1990	1991-2000	2001-2015
Fuel Oil, Diesel	22.580	(0.5)	(0.4)	0.0	0.0
Electricity	11.061	(0.2)	(0.6)	(1.0)	(1.0)
Coal	0.767	0.35	(0.1)	(0.5)	(0.5)
Natural Gas	1.246	0.15	0.2	(0.5)	(0.5)

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989 for 1982 energy intensities. Canadian Energy Research Institute for growth projections.

[a] Measured as megajoules per 1971 dollar value of output produced in 1982.

[b] Numbers in brackets represent negative growth rates, or decreased energy intensities.

TABLE 6.11

ENERGY INTENSITY OF ALL OTHER MANUFACTURING INDUSTRIES

	Annual Average Growth Rates[a] (percentages)			
	1981-1985	1986-1990	1991-2000	2001-2015
Fuel Oil, Diesel	(1.5)	(0.5)	0.0	0.0
LPG	(0.5)	(0.5)	(0.5)	(0.5)
Electricity	0.5	0.5	(0.5)	(0.5)
Natural Gas	0.5	1.0	(0.5)	(1.0)

SOURCE: Canadian Energy Research Institute.

[a] Numbers in brackets represent negative growth rates, or decreased energy intensities.

6.4 Sensitivity Cases

The reference case projections were based on assumptions of fairly steady growth in world oil prices and in Canadian manufacturing production. As a result, the base case energy intensities reflect continued, steady improvement in energy efficiency parameters. Two alternative cases were run in the SERF model in order to explore the sensitivity of the base case energy demand results to constant energy intensity parameters and stagnant exports.

These sensitivities are created in an attempt to assess the relative impacts of technological change reflected in the energy intensity parameters, and industrial growth respectively, on energy use in general, and on natural gas consumption in particular. Obviously, the two sets of assumptions are interrelated, as high growth in an industry's output allows for more investment and a faster capital turnover, also making investment in energy efficiency measures more attractive. Changing only one set of assumptions at a time, facilitated an assessment of the relative impacts of general market growth and efficiency changes. These results are to be viewed as sensitivity tests for the reference scenario and not as alternative market scenarios.

6.4.1 Constant Energy Intensity Scenario

Although prices do not enter directly into SERF, energy prices are the most important determinant of energy intensity changes. CERI's World Oil Market Model[22] provided the reference oil price scenario, which can be regarded as the highest sustainable price path under reasonable assumptions. There is substantial downside risk attached to this scenario. The effects of lower world oil prices were demonstrated by the lower oil prices of the 1980s. Declining profitability of energy efficiency investments delayed or eliminated many such projects. Lower-priced thermal fuels also slow the penetration of electricity into industrial processes.

The ISTUM results for the B.C. pulp and paper industry clearly indicated the importance of energy prices for the implementation of conservation measures at the process level, and the impact of such measures on the energy intensity coefficients.

The first sensitivity case, goes to the extreme of keeping all energy coefficients constant for the entire forecast horizon after 1985, reflecting the effects of low priced thermal fuels. A comparison of these results with the reference case indicates the magnitude of the impact of efficiency and other technological changes on final energy demand.

6.4.2 Stagnant Export Scenario

The reference case is based on assumptions of a relatively strong primary manufacturing sector, with a trend towards increasing value-added in domestic production. Exports provided much of the impetus for this manufacturing growth scenario.

In order to provide an indication of the impact on energy demand of a more slowly growing industrial sector, export growth was assumed to stagnate. The second sensitivity case therefore reflects constant values of exports from the manufacturing sector after 1985.

Substantial modelling efforts have attempted to evaluate the effect of a move away from manufacturing production towards a "service-economy." However, this sensitivity does not depict a true "service sector scenario," as the consumption patterns of households are not changed to reflect higher growth in the service sector.

Footnotes

[1] M. Jaccard and F. Bohlken, Forecasting the Demand for Energy in the B.C. Pulp and Paper Sector Using the ISTUM Model, paper prepared for B.C. Hydro and Power Authority (Burnaby: Simon Fraser University, Natural Resources Management Program, July 1988).

[2] Energy Modeling Forum, EMF Report 8: Industrial Energy Demand, vol. 2, draft (Stanford, California: Stanford University, January 1988).

[3] Canada, Industry, Science and Technology, Industry Profile, Primary Iron and Steel (Ottawa: Industry Science and Technology Canada, 1988), p. 5.

[4] Canada, Industry, Science and Technology, Industry Profile, Ferrous Foundries (Ottawa: Industry Science and Technology Canada, 1988), p. 4.

[5] Various alternative forecasts of the long-term performance of Canada's petroleum sector exist. See for example: (1) Alberta Energy Resources Conservation Board, Energy Requirements in Alberta 1986-2010, Report 86-A, vols. 1 and 2 (Calgary: AERCB, October 1986), and the update Supplementary Report, Report 88-C (Calgary: AERCB, May 1988); (2) Canada, Department of Energy Mines and Resources, Long-Term Energy Outlook 1987-2005, Working Paper prepared by Energy Market Analysis Division (Ottawa: Energy Mines and Resources, June 1988); and (3) Electric Utility Planning Council, 1986 EUPC Forecasts of Alberta's Electric Energy Requirements 1986 to 2010 (Edmonton: EUPC, September 1986).

[6] Anthony E. Reinsch, Kevin J. Brown, and James O. Stanford, Stability Within Uncertainty: Evolution of the World Oil Market, Study No. 28 (Calgary, Canadian Energy Research Institute, September 1988).

[7] Export data for specific products for 1980 through 1987 can be obtained from: U.S. Energy Information Administration, Monthly Energy Review June 1988 (Washington, D.C.: National Energy Information Centre, September 1988).

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[9] Alberta Energy Resources Conservation Board, Alberta Ethane Policy, Report on Implementation, AERCB Report 88-D (Calgary: AERCB, April 1988), and "Nova Reviews Expansion Plans," Calgary Herald, Section E, p. 1, Saturday, October 15, 1988.

[10] Alberta Energy Resources Conservation Board, Reports 86-A and 88-C.

[11] Energy Analects, October 10th, 1988, pp. 5-6.

[12] Energy Modeling Forum, EMF Report 8: Industrial Energy Demand.

[13] Canadian Industry Program for Energy Conservation, 1986 Task Force Reports (Ottawa: Energy, Mines and Resources Canada, August 1987), p. 61.

[14] Ibid., p. 23.

[15] Canada, Department of Energy, Mines and Resources, Inter-Fuel Substitution Demand Model, Financial and Market Analysis Branch, Reference case run provided for CERI, October 1988.

[16] Canadian Industry Program for Energy Conservation, p. 53.

[17] Ibid., p. 15.

[18] Reinsch, Brown, and Stanford, 1988, p. 157.

[19] Canadian Industry Program for Energy Conservation, p. 40.

[20] D. Baillard, C. Berger, A. Hauric and R. Loulou, Modelling Energy/Technology Choices in the Cement Industry of Canada Using the Markal Model, Ecoles des Hautes Etudies Commerciales, Affiliee a l'Universite de Montreal, G-87-02 (Montreal: Group d'Etudes et de Recherche en Analyse des Decision (GERAD), January 1987), pp. 9 - 12.

[21] Canadian Industry Program for Energy Conservation, p. 40.

[22] Reinsch, Brown, and Stanford.

Chapter 7

RESULTS AND CONCLUSIONS

The reference scenario and the two sensitivity cases were run through the SERF model, generating energy demand results for each energy type in each industry and for the total industrial sector. These results are based on an internally consistent outlook for the economy, with the inter-industry dependency structure taken into account and household consumption developing in accordance with the demographic structure of the country.

Section 7.1 presents the energy demand results with sensitivities for the specific industries examined in this study, and Section 7.2 provides results for the total industrial sector. General conclusions are discussed in Section 7.3, and some final recommendations for future studies are noted in Section 7.4.

The emphasis of this study is on natural gas demand. This is evident in terms of the industries selected and the discussion of technologies. The results are comprehensive, forecasting demand for all forms of purchased energy. The full scope of the results allows for a discussion of inter-fuel competition, and resulting relative market shares, providing a more complete assessment of the competitive forces acting on natural gas demand.

7.1 Specific Industry Energy Demand Results

The SERF results provided detail on energy demand from each of the four 3-digit SIC code industries examined in detail, and from the cement and aluminum smelting industries for which specific scenarios were also designed.

7.1.1 Energy Demand from the Pulp and Paper Industry

Total energy demand for this industry is forecasted to grow from 312 PJ in 1982 to 401 PJ in 2015, or close to 1 percent per year. The aggregate energy intensity of production declines on average by 0.85 percent per year. The complete energy intensity tables resulting from the growth rate assumptions of Chapter 6 are included with the detailed energy demand results in Appendix D.

Total energy demand by energy form is illustrated in Figure 7.1. Natural gas demand grows from 91 PJ in 1982 to 105 PJ in 2015, or 11.5 percent over the period while fuel oil, the other major thermal fuel, grows from 120 PJ to 127 PJ, or approximately 6 percent, over the same period. Electricity demand growth far out-paces these fuels, in accordance with the assumption of increased electricity intensity, growing at an annual average rate exceeding 2 percent, or close to 72 percent total growth, from 92 PJ in 1982 to 158 PJ in 2015.

As a consequence, the market share of electricity grows from close to 30 to almost 40 percent in the reference case, while the shares for the thermal fuels all decline, although the natural gas demand share falls less than fuel oil. These changes in relative market shares are shown in Figure 7.2.

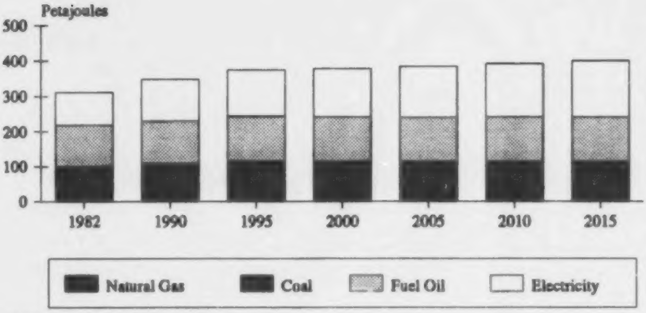
The impact on energy demand of constant energy intensity parameters is not as dramatic as for the aggregate industrial sector. Total energy demand increases at an annual average rate just above 1 percent, reaching almost 422 PJ by 2015. The thermal fuels now retain their original market shares, while the penetration of electricity is halted. This results in final purchased electricity demand of 133 PJ, or 25 PJ below the base case level. Natural gas demand increases to 122 PJ, which is approximately 17 PJ higher than the base case.

The impact of a stagnant export market is particularly severe for this highly export-oriented industry. This second sensitivity case causes total energy demand to fall significantly through the entire forecast period to a level of 308 PJ, or 93 PJ below the base case, by 2015. While the lower production levels dampen overall energy demand, the energy intensities still change in accordance with base case assumptions.

As a result, the second sensitivity case has particularly serious consequences for natural gas demand which declines towards 80 PJ, or nearly 25 PJ below the base case, by 2015. Electricity also remains significantly below the reference case level despite capturing the higher market share. Electricity demand grows to 122 PJ by 2015, almost 37 PJ below the base case results.

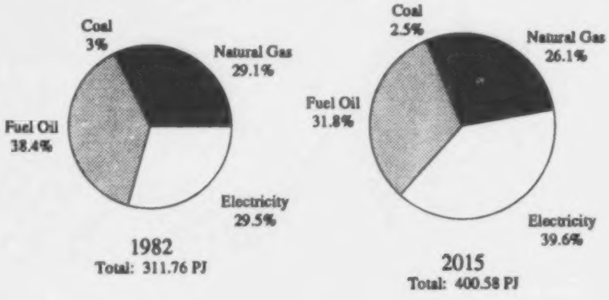
The increased electricity dependency of this industry represents a challenge to natural gas suppliers. Pulp and paper production

Figure 7.1
Pulp and Paper Industry Energy Demand
Base Case



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

Figure 7.2
Pulp and Paper Industry
Energy Fuel Shares



1982
Total: 311.76 PJ

2015
Total: 400.58 PJ

SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

is the single largest energy consuming manufacturing industry today and, as these results indicate, substantial changes in energy use patterns may take place over the next 30 years. The export dependency of this industry will place additional pressure on pulp and paper producers to invest in new technologies in a continuous effort to improve efficiency and productivity.

7.1.2 Energy Demand from the Iron and Steel Industry

Since the iron and steel industry was assumed to undergo considerable technological changes with major impacts on energy end-use patterns, it is not surprising that the results indicate a significant overall conservation potential, especially for the latter part of the forecast period. The total growth in energy demand averages less than 0.5 percent per year over the entire period, as Figure 7.3 illustrates. In fact, demand grows from 113 PJ in 1982 to a peak of 132 PJ in 2007, but declines slightly through the last decade to just below 131 PJ by 2015. Natural gas demand grows from 62 PJ to a peak of 69 PJ in 1998 and subsequently declines, approaching the initial demand level again by 2015. Both electricity and fuel oil demand grow very slowly throughout the period. Coal use is insignificant since metallurgical coal is considered a feedstock and therefore not accounted for.

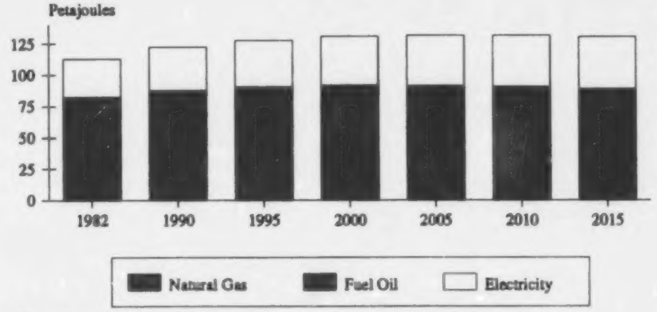
The detailed energy demand results and energy intensities from the assumed growth rates in Chapter 6 are provided in Appendix D. The aggregate intensity falls sharply at almost 1 percent per year.

As Figure 7.4 shows, the relative changes in market shares chiefly favour electricity at the expense of fuel oil and natural gas. Natural gas is expected to lose market share relative to other fuels used in iron and steel production and, as well, the size of the total market is expected to start declining in the last decade of the forecast period.

Keeping energy parameters constant at their 1985 levels for the forecast period emphasizes the importance of the base case projections of technological change to the magnitude of total energy demand. Under this first sensitivity case, demand reaches 166 PJ, 35 PJ above the reference case by the end of the period, growing 1.4 percent per year. Natural gas demand now continues to grow, reaching 91.5 PJ by 2015, almost 29 PJ above the base case result.

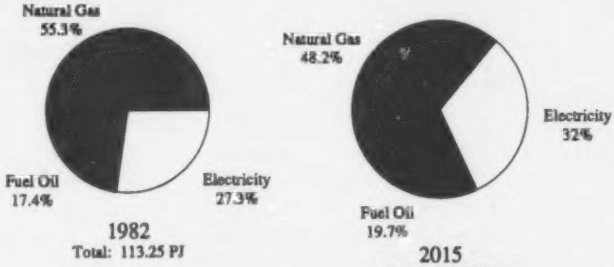
The restrained export growth sensitivity case has a relatively smaller impact on this industry, since domestic consumption of

Figure 7.3
Iron and Steel Industry Energy Demand
Base Case



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Figure 7.4
Iron and Steel Industry
Energy Fuel Shares



1982
Total: 113.25 PJ

2015
Total: 130.82 PJ

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

iron and steel dominates exported volumes. The magnitude of the changes in energy demand are therefore smaller than for the first sensitivity. Total demand now peaks in 1997 at 120 PJ, and declines to 108 PJ by 2015, some 23 PJ below the reference case level.

Keeping on top of rapid technological developments represents the major challenge for both consumers and producers of energy in this industry. The results indicate that natural gas is under competitive pressure from other energy forms, particularly electricity, and that fundamental production changes can actually reduce total energy consumption, and thereby also reduce natural gas demand.

7.1.3 Energy Demand from Petroleum Refineries

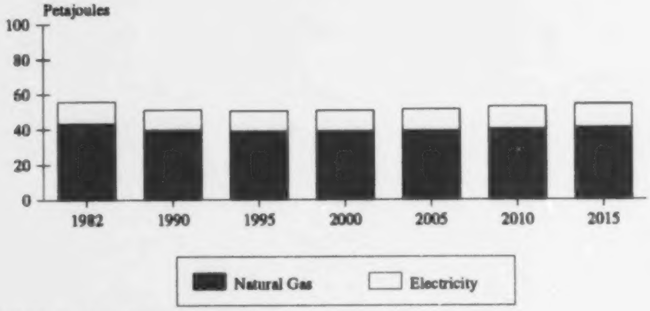
The petroleum refining sector, although a relatively small purchased energy consumer, was seen to constitute an important end-use market for natural gas. As Figure 7.5 illustrates, total energy demand is predicted to stagnate around 54 PJ in the reference case, after temporarily dipping towards 50 PJ before the turn of the century. Natural gas demand, initially exceeding 43 PJ, bottoms out below 39 PJ and recovers to slightly less than 41 PJ by 2015. Electricity demand experiences a smaller initial decline and exhibits a slight net increase from 12.4 PJ to 13.3 PJ over the forecast period.

The initial decline in total energy demand is a reaction to the capacity reductions in the petroleum refining sector realized in the 1980s. Combined with significant energy intensity reductions during the last 15 years, the net effect is a noticeable drop in total energy demand. As production again increases, efficiency improvements will initially outweigh the effect on total energy demand of higher production levels, extending the decline in energy demand into the 1990s.

Electricity and natural gas represent very close to 100 percent of purchased energy for this industry. The small shift in relative market shares in favour of electricity is barely perceptible from Figure 7.6. As the detailed results in Appendix D indicate, the assumed changes in energy intensities result in a total energy intensity decline of 0.5 percent per year.

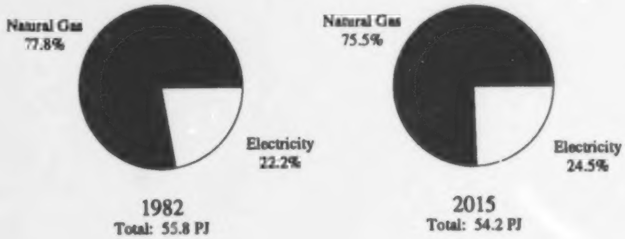
Keeping the intensity parameters constant after 1985 results in a slight but steady growth in total energy demand. Energy use grows from close to 56 PJ to almost 63 PJ. Natural gas demand accounts for most of the difference between this sensitivity and the

Figure 7.5
Petroleum Refineries Energy Demand
Base Case



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

Figure 7.6
Petroleum Refineries
Energy Fuel Shares



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

stagnant base case, reaching almost 49 PJ by 2015, compared to 41 PJ in the base case.

If export growth is halted after 1985, total energy demand falls below 48 PJ by 2015. In this second sensitivity, natural gas and electricity demand decline below 36 and 12 PJ, respectively.

The magnitudes of the changes under either sensitivity case are small, as no dramatic technological changes are foreseen and the major proportion of production is not exported. Provided that consumer expenditure patterns are not significantly altered, petroleum refineries can be expected to remain a large and stable natural gas consumer.

7.1.4 Energy Demand from the Industrial Chemicals Industry

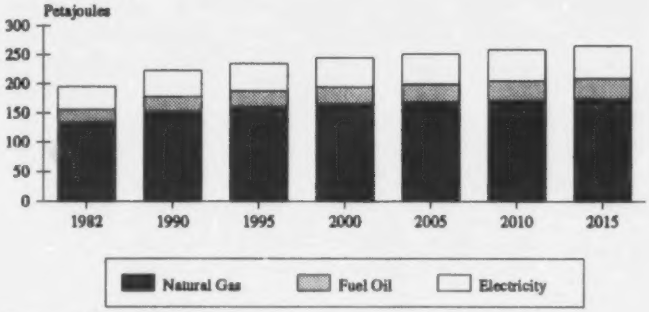
Even when feedstocks are not included, the industrial chemicals industry is the largest, natural gas consuming, manufacturing industry. Natural gas captured a market share of more than 68 percent of purchased energy in 1982. The reference case demand for energy is illustrated in Figure 7.7. Total demand increases significantly from 196 PJ to 267 PJ over the forecast period. Natural gas use grows from 134 PJ to 174 PJ, electricity from 39 PJ to 56 PJ and fuel oil from 22 PJ to almost 35 PJ by 2015.

The relative market shares are not significantly affected, although the natural gas share declines by 3 percentage points, benefiting the fuel oil and electricity shares. The evolution of these shares is shown in Figure 7.8. The aggregate energy intensity resulting from the reference case growth rate assumptions declines at a steady 0.5 percent per year. The detailed results are included in Appendix D.

Without changes to intensity parameters, the average growth in energy demand almost doubles, reaching 319 PJ by 2015. Natural gas demand increases to 218 PJ, 44 PJ above the reference case 2015 level. Electricity demand grows to 64 PJ or 8 PJ above the reference case, while fuel oil demand is almost unchanged from the base case.

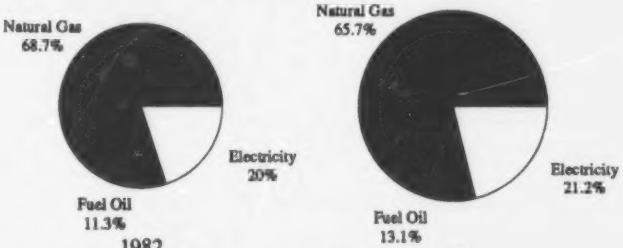
In the second sensitivity case of stagnant exports, total energy use decreases from an initial peak in 1991 of 210 PJ, to 191 PJ in 2015, some 76 PJ below the reference case level. Natural gas demand also declines to below 125 PJ by 2015, or almost 50 PJ below the base case, after peaking at 143 PJ in 1992.

Figure 7.7
Industrial Chemicals Energy Demand
Base Case



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Figure 7.8
Industrial Chemicals
Energy Fuel Shares



1982
Total: 196.02 PJ

2015
Total: 266.92 PJ

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

The industrial chemicals industry is forecast to remain a major natural gas consumer. The penetration of electricity at the expense of natural gas, in terms of relative market shares, is less significant than for the pulp and paper industry, but should be noted as a definite trend. This industry has been very successful in implementing energy efficiency measures to date. However, even with the energy intensity changes assumed in the reference case, reflecting continuation of such efforts, total energy demand exhibits significant growth. If technical changes are slower to penetrate, the constant energy intensity sensitivity case illustrates that the growth rate for total energy demand could almost double. Again, this emphasizes the importance of continued research and energy management efforts in this large energy using industry, in order to control production costs and improve productivity.

Total energy demand growth is also significantly affected by the export outlook for the industry, which was considered quite positive in the reference case.

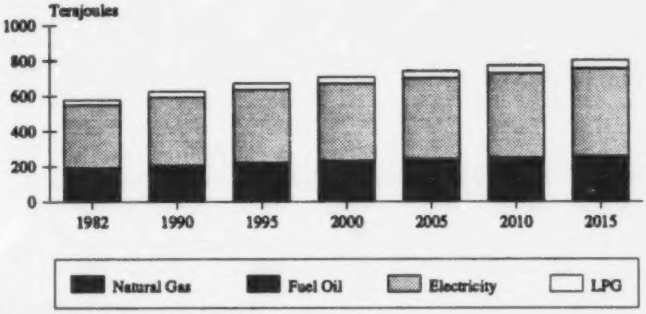
7.1.5 Energy Demand from the Mixed Fertilizer Industry

Some inconsistencies in the way the SERF Model treats this industry severely hampered the generation of reliable results. Essentially, production is shifted almost entirely from the fabrication and assembly (manufacturing) sector to the mining sector over the forecast period. Assuming that the energy intensity of production of fertilizer is the same regardless of which sector it is produced in, total energy demand results were generated by adding the production from both sectors and calculating the energy required to produce the total output of fertilizer in each year.

It also remains unclear how SERF's mixed fertilizer category relates to the agricultural chemicals industry sector as specified by Statistics Canada, which is a much larger energy user even when feedstocks are not accounted for.

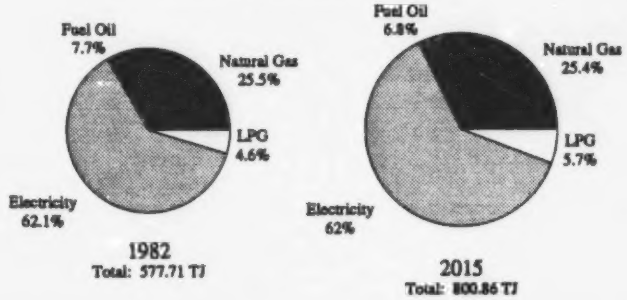
The reference case results are illustrated in Figure 7.9. Total energy demand grows by almost 1.2 percent per year from close to 580 TJ to more than 800 TJ by 2015. These energy demand figures are small compared to the other industries considered, since the exclusion of feedstock demand eliminates the large natural gas volumes used in production of ammonia. By comparison, the Canadian Fertilizer Institute reported natural gas consumption of 154 PJ in 1987.[1]

Figure 7.9
Mixed Fertilizer Industry Energy Demand
Base Case



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Figure 7.10
Mixed Fertilizer
Energy Fuel Shares



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Note: Energy volumes for these figures are measured in terajoules since the totals are much small than for the other industries.

Relative fuel shares remain virtually constant over the forecast period, as Figure 7.10 shows. Natural gas captures approximately 25 percent of total energy use, and electricity's share is in excess of 62 percent.

Total energy intensity declines at an annual average rate of 0.6 percent in the reference case. With constant energy intensity, total energy demand would grow at close to 2 percent per year, reaching almost 1 PJ (951 TJ) by 2015.

Limiting export growth, on the other hand, has very little effect on energy demand. Total demand growth averages approximately 1 percent per year, exceeding 770 TJ by 2015, only 30 TJ below the base case. The full details of these results are found in Appendix D.

The fertilizer industry is only a significant energy consumer when feedstock demands are taken into account. The fact that SERF at this stage fails to do so makes it difficult to draw any interesting conclusions from the results. Although efficiency changes are of importance to energy consumption levels, clearly process changes aimed at better utilization of feedstock will have a much greater impact on natural gas demand.

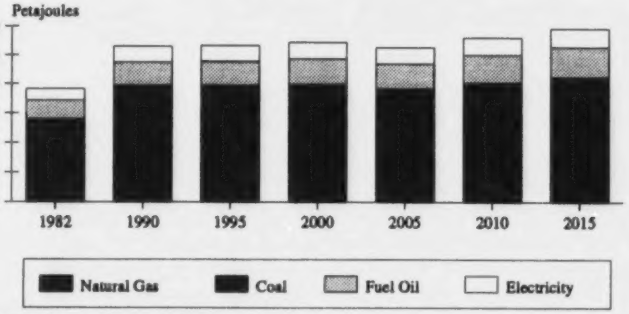
7.1.6 Energy Demand from the Cement Industry

Total energy demand in cement production grows at approximately 1.7 percent per year, from 38 PJ to 59 PJ over the forecast period. Natural gas constitutes the largest single energy source, growing from almost 17 PJ to 24 PJ by 2015, as Figure 7.11 indicates. Demand for the second largest energy form, coal, also exhibits substantial growth over the period, from 11 PJ to well over 18 PJ in 2015. Detailed results can be found in Appendix D.

In terms of market shares, the natural gas share decreases slightly, mostly to the benefit of coal, which increases its relative share by 2 percentage points. The evolution of these shares is shown in Figure 7.12.

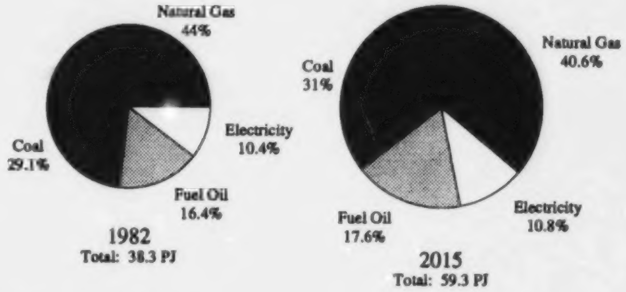
Total energy intensity declines by a little less than 0.5 percent per year as a result of the detailed intensity assumptions from Chapter 6, reflecting the steady penetration of more energy-efficient technologies. If the intensity parameters are kept constant, the energy demand growth rate doubles. Under this first sensitivity, total energy

Figure 7.11
Cement Industry Energy Demand
Base Case



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Figure 7.12
Cement Industry
Energy Fuel Shares



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

demand reaches almost 70 PJ by 2015, or 11 PJ above the base case results. Natural gas demand grows to almost 30 PJ, or 6 PJ more than the base case, and coal to 22 PJ, or 4 PJ above the base case results in 2015.

Although this industry, like the iron and steel industry, produces predominantly for the domestic market, the stagnation of exports has a significant effect on total energy demand. In this second sensitivity case, total energy demand increases to just above 43 PJ, or 16 PJ lower than the base case. Natural gas demand approaches 18 PJ and coal demand exceeds 13 PJ, approximately 6.5 PJ and 5 PJ below the base case, respectively.

These results indicate that the cement industry will remain a very important energy user, with growing demand for total energy in the future. The flexibility of this industry with respect to fuel choice and the potential savings involved from investment in energy efficient technologies, as illustrated by the first sensitivity case, underlines the importance of understanding and anticipating the needs of this energy consuming industry.

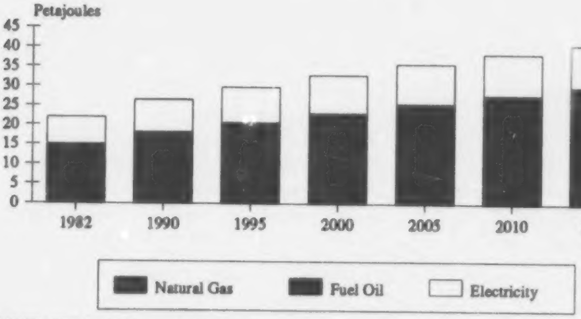
7.1.7 Energy Demand from the Aluminum Smelting Industry

The aluminum smelting industry is another industry where energy demand is slated to undergo substantial growth. At an average annual rate of more than 2.5 percent, total energy demand grows from 22.5 PJ to almost 42 PJ by 2015. Figure 7.13 illustrates this growth, broken down by energy form. Natural gas has a relatively small share of this total, growing from 0.8 PJ (783 TJ) to 1.5 PJ (1461 TJ) by 2015. The industry is a large user of fuel oil and electricity. Fuel oil consumption doubles from 14 PJ to well above 28 PJ, while electricity use increases from 7 PJ to almost 11 PJ in 2015.

In terms of market shares, natural gas maintains its 3.6 percent share, while fuel oil intensity increases, capturing 5 percentage points from electricity's relative share. This development is portrayed in Figure 7.14.

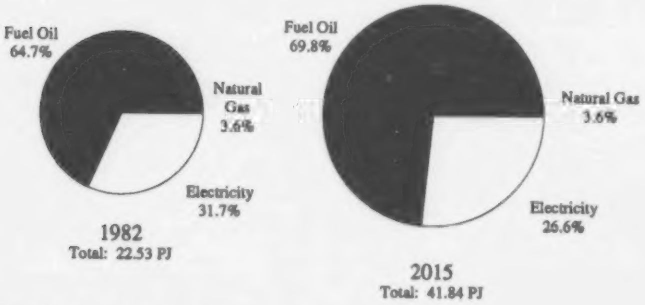
Total energy intensity of production decreases only slightly, approximately 0.3 percent per year in the base case. The effect of assuming constant energy intensities is still relatively strong, as total energy demand grows at a rate of 3.2 percent per year, reaching close to 46 PJ in 2015, or almost 4.5 PJ above the base case. Natural gas

Figure 7.13
Aluminum Smelting Energy Demand
Base Case



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Figure 7.14
Aluminum Smelting
Energy Fuel Shares



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

demand now increases to 1.6 PJ (1633 TJ), while electricity demand becomes 14 PJ and fuel oil demand almost 30 PJ.

The effect of stagnant exports is also significant. Total energy demand reaches only 34.5 PJ by 2015. Natural gas demand increases to 1.2 PJ (1204 TJ), while fuel oil demand exceeds 23 PJ and electricity demand reaches almost 9 PJ in 2015.

As noted in the intensity assumptions for this industry, the fuel oil category is slightly misleading. Petroleum coke and pitch used as catalyst materials may represent close to half of the refined petroleum products categorized as fuel oil. The forecast was based on a rather conservative assumption of constant petroleum products intensity after year 2000. The MARKAL model of Quebec's aluminum industry indicates that natural gas may penetrate to a market share of 14 to 16 percent by 2005. This penetration is achieved primarily through reduction in the share of fuel oil, excluding catalyst materials.[2]

This industry is traditionally viewed as a captive electricity market of minor concern to the natural gas industry. However, these results suggest that a significant natural gas market could potentially be developed in aluminum smelting. Not only should natural gas be able to capture some of the large and growing share of fuel oil, but the advantages of natural gas-fired, cogenerated electricity should be explored. The SERF forecasts portray the industry as a growing energy consumer and the current distribution of fuel shares poses a challenge to natural gas.

7.2 Energy Demand Results for the Industrial Sector

7.2.1 Model Problems and Adjustments

The process of running the SERF model revealed some major inconsistencies in the way feedstock volumes were handled. This became evident from the coal results. It transpired that supply data including metallurgical coal feedstock volumes were matched with demand data without coal feedstocks. To solve this imbalance, the model would randomly allocate excess coal supply to any unsaturated demand category. In other words, metallurgical coal was predicted to penetrate all sectors ranging from commercial and transportation to an unknown component of forecasted industrial coal consumption.

For the specific industries analyzed, this inconsistency problem was eliminated by recalculating the original demand data measured in joules, based on the industry-specific values of each energy form per joule.

In addition, the fabrication and assembly sector includes all secondary generation of electricity, a topic outside of the scope of this study. As the reference scenario contained no specific choices for electrical generation technology, SERF assumed that thermal electricity generation continued to be dominated by coal-fired generation capacity.

Because of the industrial categories included and the feedstock problems in SERF, initial industrial sector energy demand results exhibited considerable growth in coal demand. Coal captured a relative market share of 35 percent in 1982 growing to 49 percent by 2015, completely overshadowing any other energy demand trends in this sector.

The market share of coal in the industrial sector was calculated to be 3 percent in 1981, excluding coal use for thermal electricity generation and coal feedstocks for iron and steel production. In order to get a meaningful assessment of total industrial energy demand, this relative share of coal was arbitrarily held constant for the forecast period.

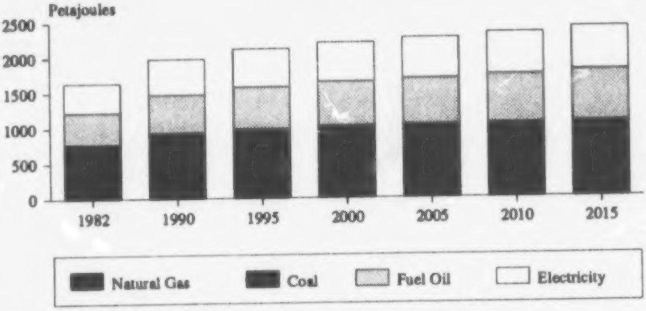
The manufacturing industries in this study are distributed over three of the six industrial sectors in SERF, since some are classified as primary industries and are not included in the fabrication and assembly component (see Appendix C).

The total industrial sector is constructed as the sum of all the production sectors including forestry, construction, mining, primary energy production and fabrication and assembly, but excluding secondary electricity generation, fisheries and agriculture.

7.2.2 Reference Case Results

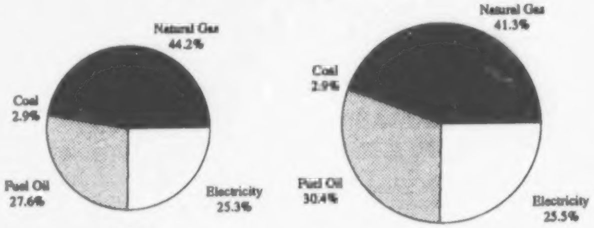
Total energy use in the industrial sector increases by more than 1.4 percent per year, from 1650 PJ in 1982 to 2432 PJ in 2015. Figure 7.15 illustrates this growth in total energy demand and the demand for the four largest energy carriers. Natural gas demand grows from 723 PJ in 1982 to 996 PJ in 2015, slightly over 1 percent per year.

Figure 7.15
Total Industrial Energy Demand Base Case



SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

Figure 7.16
Total Industrial Sector Energy Market Shares



1982
Total: 1649.91 PJ

2015
Total: 2431.57 PJ

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

While the demand for all energy forms is seen to increase in absolute terms, different relative growth rates lead to changes in relative market shares as illustrated in Figure 7.16. The market share of natural gas declines from 44 percent to 41 percent. The market share of fuel oil, by comparison, increases by almost 3 percentage points. Natural gas demand is predicted to grow more slowly than both electricity and fuel oil, indicating that the competitive pressures on natural gas end-use markets are considerable. The detailed tables of results are included in Appendix D.

7.2.3 Constant Energy Intensity Case Results

The first sensitivity case was designed to measure the importance of the assumptions regarding energy intensities, reflecting trends in conservation, efficiency and penetration of new technologies as outlined in Chapter 6. When these intensities are left unchanged, the relative market shares of each energy form remain constant compared to the base year. This sensitivity case is, therefore, only used to shed light on the magnitude of the total impact the intensity parameter assumptions make on energy demand, not on the relative market shares captured.

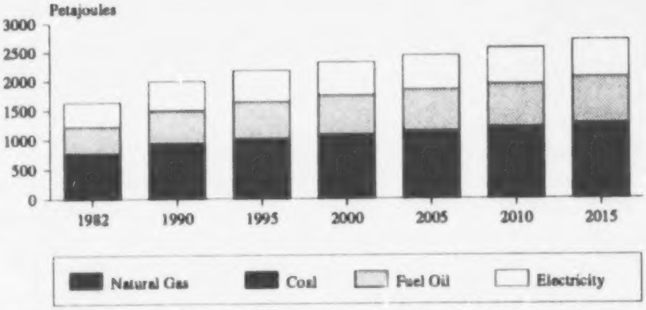
Figure 7.17 shows the growth in energy demand under this sensitivity case. Total energy demand reaches 2733 PJ in 2015, or 301 PJ higher than the base case, representing an annual growth rate of almost 2 percent. Natural gas demand grows to 1189 PJ by 2015, or 193 PJ higher than in the base case.

7.2.4 Stagnant Export Case Results

In this sensitivity the relative market shares change in the same pattern as in the base case, since the same energy intensities are applied. As Figure 7.18 indicates, the magnitude of the changes in demand are even greater than in the constant energy intensities case. A stagnant export market leads to energy demand growth of only 0.6 percent per year, for a total of 1970 PJ in 2015, or 461 PJ below the base case. However, the natural gas demand of 803 PJ by 2015 indicates that the negative impact of export stagnation, 192 PJ lower than the reference case, is of the same magnitude as the positive impact of constant intensities.

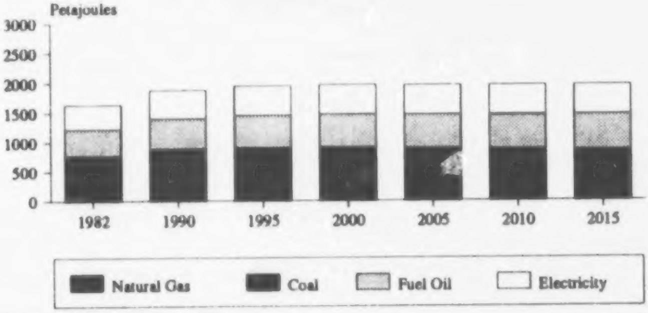
Based on these results, industrial growth appears to be the more important driving force behind total energy demand. The technological change assumptions reflected in the energy intensities have an

Figure 7.17
Total Industrial Sector
Energy Sensitivity Case



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

Figure 7.18
Total Industrial Sector
Export Sensitivity Case



SOURCE: The Socio-Economic Resource
Framework, University of Waterloo,
March 1989.

important, but more gradual and somewhat smaller effect on total energy demand. For natural gas the relative impact of the two sensitivities is almost identical. This indicates that inter-fuel competition and process efficiency changes are as important a threat to the size of natural gas markets as a stagnant manufacturing sector.

7.3 Conclusions

This study attempts to convey an idea of the complexities and conflicting trends that underlie the slow-changing, total industrial demand for energy in general, and industrial natural gas demand specifically. The reference case assumptions made for the SERF model represent only one possible view of developments in these conflicting industry-specific trends. The numerical results should be regarded as illustrations of the impact which these long-term trends can have over a sufficient time-period, as opposed to forecasts of actual energy use.

7.3.1 Potential Energy Efficiency Improvements

Although demand management and improved energy efficiency have received much attention, there is a lack of comprehensive work illustrating total potential savings in the industrial sector and the impacts on energy use patterns. This report indicates that under a reasonable technology evolution scenario, overall industrial sector energy intensity can decline by around 0.5 percent per year. The reference scenario total energy demand of 4597 PJ is substantially (376 PJ) lower than when energy intensities are left unchanged.

- Technological changes in production processes can contribute substantially to reducing the growth in total energy demand in the industrial sector.

7.3.2 The Impact of Efficiency Improvements on Natural Gas Demand

In terms of the impact on individual energy forms, natural gas consumption of 996 PJ in 2015 is 193 PJ lower than if energy intensities are constant for the forecast period. In other words, of the total reduction in energy demand volumes attributed to technological changes in the reference case relative to the constant energy intensity case, more than half comes from reduced natural gas volumes.

- Although total industrial natural gas demand is growing, new production technologies indicate a particularly high potential for efficiency improvements in natural gas utilization.

7.3.3 The Link Between Energy and Capital

Both the energy supplier, seeking to maximize sales revenues, and the industrial energy consumer, seeking to produce a competitive product, recognize that energy consumption choices are part of an integrated decision process. Energy consumption is the outcome of capital investment decisions determined within the framework of total productivity, product quality and the working environment. Ultimately the demand for energy in the industrial sector is derived from the demand for the industrial consumers' final product.

- In view of the potential energy savings demonstrated, industrial energy consumers should strengthen their commitment to energy efficiency improvements, recognizing that energy consumption must be approached in the wider context of capital investment decisions and long-term production goals.

7.3.4 Promoting Technological Change

From the perspective of natural gas suppliers, these results emphasize the importance of not only understanding but anticipating and developing solutions to their industrial customers' energy needs. In order to retain their market share in an industrial market characterized by intensified inter-fuel competition, with consumers seeking highly energy efficient technologies, natural gas suppliers should actively support the development and dissemination of such technologies. For example, if natural gas is to retain its share of the shrinking iron and steel reheat market, continued applied research into furnace designs and high efficiency burners must be pursued.

- Natural gas suppliers should enhance efforts in research and development of efficient natural gas-based production technologies.

7.3.5 The Role of Advanced Electro-Technologies

The total industrial sector did not display a tendency towards increased penetration of electricity, although the results indicated that some of the most energy-intensive industries, in particular pulp and paper, may experience strong growth in electricity demand. This lack of an overall electrification trend is in itself notable, considering the amount of interest in and the touted potential of advanced electro-technologies. The conclusion that electricity is not likely to increase its relative market share in the industrial sector was based on two premises.

- To a large extent, the electro-technologies penetrating energy-intensive industries replace less efficient electricity-using equipment, leading to a net conservation effect on electricity consumption.

- Penetration of electricity-using technologies at the expense of thermal-fired equipment is mostly limited to the relatively small, specialized market of high value-added production, which does not have a substantial impact on total industrial energy demand.

7.3.6 Pursuing Cogeneration Options

In the discussions of electricity intensity in the context of individual industries, cogeneration potential was revealed as a major area of uncertainty. The assumptions specified in the reference case scenario included some penetration of natural gas-fired cogeneration in the high-potential industries, but the technical potential for cogeneration remains largely unexploited. Actual penetration will be a function of financial parameters, such as utilities' buy-back rates and cost of capital equipment. Renewed political emphasis on demand management represents a positive signal in this context.

- Natural gas suppliers should realize the important potential impact of cogeneration technologies and take an active role in pursuing cogeneration opportunities.

7.4 Recommendations

Problems were encountered in interpreting and applying regional, industry-specific process data to a national modelling framework. Process modelling in Canada has grown out of regional needs and region-specific industrial characteristics. The existing models are, as a result, very different in structure and approach. With the regional expertise now existing, increased communications between process modelling groups in Canada is desirable. A more comprehensive coverage of the industrial processes in Canada should be promoted without loss of the regional detail so uniquely available in such models.

SERF remains the only Canadian model in existence with the capability to generate such detailed results and respond to such specific assumptions as this study required. An interesting follow-up study may be to provide the regional break-down of industrial energy demand when the SERF database is regionalized.

Aside from some discussion of the cogeneration potential, the question of optimal technology choices for generation of electricity was not explored in this study. The SERF results confirm that this is an issue of major importance for energy demand.

This study has demonstrated the diversity of energy demand patterns across manufacturing industries and the impact evolving production technologies can have on energy demand. To enhance our understanding of industrial energy demand, it is necessary to commit resources to the upkeep and improvement of the state of process modelling in Canada and to the collection of consistent and meaningful data on energy use by manufacturing industries.

Footnotes

[1] Canadian Fertilizer Institute, Annual Report 1987 (Ottawa: Canadian Fertilizer Institute, 1988).

[2] D. Baillard, C. Berger, A. Harvie, and R. Loulou, Modelling Energy/Technology Choices in the Smelting and Refining Industry of Canada: The Markal Approach, Ecoles des Hautes Etudes Commerciales, Affiliee a l'Universite de Montreal, G-87-03 (Montreal: Group d'Etudes et de Recherche en Analyse des Decision (GERAD), January 1987), p. 33.

APPENDIX A

DATA SOURCES

Appendix A

DATA SOURCES

Caution must be exercised when choosing and using any set of numbers representing industrial energy use. There are various sources for such data, and the numbers can vary widely across sources due to differences in definitions, reporting and collection methods and origin of information. It is therefore necessary to ensure that the numbers used correspond as closely as possible to the aspects of industrial energy use one wishes to analyze.

For the purpose of econometric analysis, historical time series are required. There are three such sources of time series on energy use by 2-, 3- and/or 4-digit SIC code industries. These are examined in some detail below. For end-use data, the variety and divergence of data sources are great, each model requiring the creation of its own unique data base with highly researched and specialized input. The regional process data sources examined for this study are discussed in Appendix B. The description of data in this section will be limited to an overview of some of the large, nation-wide data sources available for industrial energy use analysis.[1]

A.1 Consumption of Purchased Fuels and Electricity

Statistics Canada's Catalogue No. 57-208, "Consumption of Purchased Fuels and Electricity (CPFE),"[2] is the main publication of energy data from the Census of Manufacturers. It represents the most detailed and universal coverage of industrial energy users. The 3- and 4-digit SIC code detail has only been reported in Statistics Canada Catalogue No. 57-208 since 1975. Prior to this, Statistics Canada Catalogue No. 57-506 covered the 2-digit industries for the 1962 to 1974 period. It becomes impossible to disaggregate beyond the 2-digit level prior to 1975 on a consistent basis.

Although CPFE has close to universal coverage, the series is still biased towards large energy consumers as the majority of smaller manufacturing companies are only required to complete the census' short form, which contains mostly financial data. Reported expenditure on energy is not broken down into individual fuel types and no volumes are recorded on the short form.

As is indicated by the publication's name, the series covers only purchased, not self-produced, energy forms. This means that self-generated electricity, whether hydro-, thermal- or co-generated, is excluded, as are self-produced hog-fuels, spent pulping liquor, off-gases, etc. Self-produced fuels are a very important energy source for a number of the most energy-intensive industries in Canada. For example, the pulp and paper industry consumes large amounts of wastes. The smelting and refining of metals requires a great deal of electricity, much of which is self-produced. The petroleum refining industry consumes fuels from its own refining process. This data base does include purchased fuels used for generating electricity, but these amounts cannot be separated out since no end-use information is available.

Furthermore, the numbers represent only energy uses and therefore exclude any feedstock applications of fuels. The exclusion of feedstock applies to natural gas used in the chemical industries, coal and coke used in iron and steel mills, and crude oils used by petroleum refineries. This is misleading, since a portion of the purchased volumes is used as energy. For example, the coke used in a steel mill is both a chemical reducing agent and a fuel, and a portion of the natural gas feedstock to a chemical plant is burned. If one wishes to analyze the final demand rather than the energy use of a fuel, the feedstock numbers are essential, since they represent large volumes.

Changes in definitions and methodology over time have also led to some serious discontinuities in the series. A major change was the new 1980 SIC classification standard adopted by CPFE in 1983. Further discontinuities are caused by confidentiality requirements. To exclude the possibility of calculating confidential numbers from the "total" numbers, data points are occasionally missing even at the 2-digit level. Finally, when the reporting of total fuel costs from small companies commenced in 1982, this was included under the heading "other fuels," causing a jump in this series.

For comparisons across fuels, it is often necessary to convert the volumes from natural units to energy content. This presents some problems within the CPFE series. From 1962 to 1972 only total fuel oil volumes are reported. It is hard to attach a "representative" heat content value to these numbers. Similarly, for the entire series, coal and coke represents a mixture of coal, lignite, bitumen and coke, with the heat content of this mixture unknown.

Because of the collection method, the CPFE publications are at least 2 years out of date. A further serious limitation is that after 1984 no quantity data are published.

A.2 Quarterly Report of Energy Supply-Demand in Canada

The Quarterly Report of Energy Supply-Demand (QRESD) is published in Statistics Canada Catalogue No. 57-003.[3] This frequent and more up-to-date report is based on monthly and quarterly surveys of energy suppliers and government agencies. The report is presented in a balance sheet format and provides an overview of the disposition and flow of energy through the economy. The manufacturing detail is limited to the six largest users: pulp and paper, iron and steel, smelting and refining, cement, chemicals and petroleum refineries, as well as an "other" and a "total" manufacturing category.

It is important to note that the data does not represent first-hand information from the users of energy. This opens the door to potential data errors, since it is frequently difficult to identify who the final user is. For example, one consumer may fit into several SIC classifications, but be recorded only under one. The vertical integration of a purchaser can also make it difficult to distinguish whether the energy is used, for example, in the company's mining operation, for transportation purposes, or in the manufacturing plant. Even if the numbers accurately capture the sales to the final consumer, there may be a disparity between sales and actual consumption due to inventory changes.

The detail on subsector consumption is only available from 1978. Even so, this makes up a sufficiently long time series for econometric estimation. However, several discontinuities and changes in methodology necessitate modifications to the data for a continuous series. In the industrial sector, the inclusion of steam and liquid petroleum gases (LPGs) in 1980 was a major change.

For the individual industries, energy use is measured in the final energy forms, so that electricity generated thermally in the plant is accounted for, but the fuels used for this generation are not. The primary fuels used and conversion losses appear only under aggregate industrial consumption. Producer consumption and feedstocks are likewise only accounted for as a total, not for any industrial subsectors.

Measuring transformed rather than primary energy use means that the link between energy consumption and the production of the product is much stronger, but it does not provide an adequate measure of the final demand for a fuel.

A.3 Canadian Industry Program for Energy Conservation

This program (CIPEC) was initiated in 1976 as a voluntary, industry organized program with government support. The industries report on energy use through 16 task forces. The coverage of the large and intensive energy users is excellent. These task forces set individual, voluntary goals for energy conservation and provide annual progress reports. The data is gathered by industry associations or by the companies that make up a particular task force, through direct surveys.[4]

The purpose of this data is to provide a basis for measuring energy efficiency improvements. Efficiency is defined such that any activity that increases physical output without a corresponding, proportional increase in purchased energy inputs will result in higher energy efficiency. The advantage of using physical units rather than the value of output is the closer link to production. However, it does not capture the increased quality of a product. The energy efficiency index is for some task forces further adjusted to eliminate the effect of changes in the mix and quality of raw materials and products, variations in weather and regulatory changes.

The final data is only available at the national level in the aggregate, annual report form. The data does not include fuel used for non-energy purposes, such as feedstocks. For some industries, the use of waste fuels is not included. For these industries, a shift away from purchased to self-produced fuels would result in apparent increased efficiency although, for example, the burning of biomass may be physically less efficient than burning purchased natural gas.

The greatest advantage of this data is that it is collected and reported by industry personnel involved in energy use, so that it represents first hand information from expert sources.

A.4 Statistics Canada Input-Output Division

All the manufacturing sector data in the occasional Statistics Canada Catalogue No. 15-201E, "The Input-Output Structure of the Canadian Economy,"[5] originates from the Census of Manufacturers. The publication contains a "make" matrix (a table of value of material outputs), a "use" matrix (showing the value of material inputs), and a final demand matrix. The matrices are published both in current and constant dollars, at two levels of aggregation of industrial subsectors for national totals. There is a finer level of disaggregation that is calculated but not published due to confidentiality constraints. Provincial data are also available at the medium level of aggregation for Ontario and Quebec, but only in the most aggregate form for the other provinces.

The usefulness of this data is fairly limited, since energy intensities are available only as values. The lack of average price information prohibits computation of quantity data. Furthermore, there is little information on individual fuels, and the series is always very outdated since compilation and checking is an enormous task.

The Input-Output Division has also created a special data base for their Static Energy Model. In this data base, physical quantities of individual energy inputs are related to produced output. Feedstock data are included and self-generated electricity is considered as a separate energy form. The usefulness of this data is unfortunately limited by the wide and irregular gaps between the years in the sample and by the outdated final numbers.

A.5 Energy, Mines and Resources

The Department of Energy, Mines and Resources (EMR) does not collect original data, but some of their compilations of Statistics Canada data deserve mention. The Energy Statistics Handbook contains monthly economic indicators for individual energy intensive industries and sales of natural gas, electricity and coal by sector and province. However, the energy information contains no detail on oil products or on industrial sub-sectors, with the exception of coal used by the steel industry.

The Industrial Energy Division of EMR has developed a data base that contains a large quantity of economic data, as well as total cost and quantity of energy, for 2-, 3- and 4-digit SIC code industries by province. The large, econometric Inter-fuel Substitution Demand Model (IFSD) developed by EMR also has its own data base derived from the QRESD series and modified to ensure consistency. However, this data base has no sub-sectoral detail, treating the industrial sector as a whole.

A.6 Canadian Pulp and Paper Association

This trade association possesses the most detailed energy data base of any Canadian industry. It is based on a mill-specific survey with almost 100 percent coverage and covers 13 purchased and self-produced energy forms, with motive and boiler electricity end-use reported separately. It is also subdivided by all the major products. The quality of reporting and collection is naturally very high, since it is done by industry experts. The disaggregated data is not publicly available due to confidentiality restrictions, but CERI was able to secure access to the data for a study on energy intensities.[6]

A.7 Canadian Energy Audit Program

This program started out as the Energy Bus in Ontario in 1975 and was expanded to all provinces by 1978 with the support of the federal government. It was taken over as a federal program for seven provinces in 1984 and subsequently abandoned in 1986. Alberta, Manitoba and Quebec have continued the program provincially.

The purpose of the program is to provide audits of companies in order to identify energy conservation potential; however, the problems in using the data for energy analysis are prohibitive. The audited companies do not constitute a representative sample, since primarily small firms participated. Larger companies generally carry out their own audits. Secondly, the original audit data is not updated unless the company is reaudited, so that cumulative numbers are outdated and unreliable. The data shows potential savings by energy form and 3-digit industry.

A.8 Industrial Energy Services Program

The Ministry of Energy in Ontario has generated data from its Industrial Energy Services Program. This program consists of an offer to industries to audit their plants to identify potential savings from energy efficiency improvements. The collected data is available only in aggregate form, and not by SIC code, due to confidentiality restrictions. The numbers indicate where the greatest energy efficiency potential exists and the payback periods of the investment required to achieve it. The areas for energy efficiency potential are divided into process changes, boiler combustion, electrical, space heating and cooling, steam and scheduling. Although not of quantifiable use to the present analysis, the data provides some indication of the areas where technical change in the form of energy efficiency improvements are most likely to take place.[7]

Footnotes

[1] The overview of data sources is derived from our own primary analysis aided by: William G. Mathews Associates Ltd., A Guide to the Sources of Energy Use Statistics for the Industrial, Commercial, Agricultural and Institutional Sectors of the Canadian Economy, Phase II of report prepared for the Industrial Energy Division, Energy Conservation and Oil Substitution Branch, Energy, Mines and Resources Canada (Ottawa: Department of Energy, Mines and Resources, March 1985).

[2] Canada, Statistics Canada, "Consumption of Purchased Fuels and Electricity," Catalogue No. 57-208, Annual (Ottawa: Statistics Canada, 1962-1984).

[3] Statistics Canada, "Quarterly Report of Energy Supply-Demand," Catalogue No. 57-003, Quarterly (Ottawa: Statistics Canada, 1978-1988).

[4] Canadian Industry Program for Energy Conservation, "Taskforce Reports," Annual (Ottawa: Energy, Mines and Resources Canada, 1975-1987).

[5] Statistics Canada, "The Input-Output Structure of the Canadian Economy," Occasional (Ottawa: Statistics Canada, 1981).

[6] CERI has previously obtained access to the CPPA database for a study on the pulp and paper industry, see: Ellen F. Battle, Energy Efficiency in Canada's Pulp and Paper Industry, Study No. 23 (Calgary: Canadian Energy Research Institute, October 1986).

[7] Ontario Ministry of Energy, Industrial Energy Services Program, A booklet describing the program (Toronto: Ontario Ministry of Energy, October 1987).

APPENDIX B

REGIONAL PROCESS MODELS IN CANADA

Appendix B

REGIONAL PROCESS MODELS IN CANADA

For the penetration of new technologies, results from various regional Canadian process models and data bases were assessed. A brief overview of these sources of end-use information by consumer-region is provided below.

B.1 The MARKAL and MEDEQ Models in Quebec

Quebec is the region with by far the largest amount of industrial process information. There are two extensive process-type models, MARKAL and MEDEQ, that are both presently running and have been tested for several scenarios. These models are quite different in their structure and approach to modelling the Quebec energy sector.

MARKAL is a linear programming model developed under the auspices of the International Energy Agency (IEA). It has been implemented in Quebec by the GERAD group which is associated with the University of Montreal.[1] It is a demand-driven model oriented to long-run analysis of energy and technology choices for a country or region. The input consists of techno-economic coefficient matrices for each production process.

The global MARKAL-Quebec model has various sub-models for components of the Quebec energy system: MARKAL-Production, an energy supply model for the province; MARKAL-Refineries, a detailed model of the oil refinery sector; and various industry models such as pulp and paper, cement and aluminum production. The emphasis of MARKAL is on the supply side of energy modelling. It calculates the least expensive way of meeting projected product demand for each industry with the energy resources available, choosing an optimal technology and evaluating energy forms at an iterated market price.

In contrast, the MEDEQ model has a demand-side emphasis. MEDEQ was originally developed at the Institut Economique et

Juridique de L'Energie, Universite des Science Sociales, Grenoble, France, as MEDEE. It has been modified and implemented in Quebec by the INRS-Energie in cooperation with the Quebec Ministry of Energy and Resources and Hydro-Quebec.[2]

By specifying a GNP growth scenario broken down to subsectors as physical output paths for individual industries, as well as forecasted prices for the 12 energy forms included in the model, MEDEQ will choose the optimal production processes and calculate energy demand for four heavy industries at the 2-digit SIC code level. These heavy industries are further divided into 15 subsectors, with six processes per sector and five end-uses per process. The demand for heavy oil is calculated separately in a refinery model that also chooses the optimal technical process.

B.2 The INDEPTH Model and the Large Energy User Data Base in Ontario

The main source of end-use data for Ontario is the data base for Ontario Hydro's version of EPRI's INDEPTH model. At present, the model adaptation to Ontario is close to being completed for the cement, iron and steel, and pulp and paper industries. Additional industries will be included as time permits. Ontario Hydro also has an accounting type end-use model for 14 industries and 90 processes, which is now being replaced by INDEPTH. It was not possible to conduct independent process runs on INDEPTH, but discussions with Ontario Hydro personnel regarding the energy intensity forecasts were very helpful, and data from documentation of the U.S. version of the model has also been useful.[3]

Another potential source of process information in Ontario is a survey of large energy users in Ontario undertaken by CERI Energy Research Ltd. in the spring of 1988. The survey covers large industrial users at the 4-digit SIC code level. Questions were asked about both the purchase and actual consumption of six energy forms, and the amount of interruptible versus firm purchase service where applicable. The end-use specifications for the fuels are boiler, process heat or feedstock use. The survey also generates data on the percentage of fuel use that is switchable, related storage capacity, and on-site generation of electricity and generates an inventory of the characteristics of the boilers presently in use.

B.3 The AERAM Model in Alberta

The Alberta Research Council's (ARC) AERAM linear programming model contains a detailed specification of the petrochemical industry. The model covers the industry in Alberta, considering transportation, capital, operating costs and feedstock availability and costs. Using a 3-step demand curve for five North American demand regions and energy input prices, the model generates development profiles for the petrochemical producing industry by maximizing the sum of producer and consumer surpluses.

AERAM contains an energy input-output matrix for 13 petrochemical products, where new production technologies are specified and incorporated either in the form of reduced capital and/or operating costs or by including an alternative technology matrix.

B.4 The ISTUM Model in British Columbia

The major energy-intensive industry that differentiates British Columbia from the other consuming regions is the pulp and paper industry. The Natural Resources Management Program at Simon Fraser University has recently completed an adaptation of the micro-computer version of the Industrial Sector Technology Use Model (ISTUM) for B.C.'s pulp and paper industry. ISTUM was originally developed as a mainframe model by Applied Energy Services Inc. for the U.S. Department of Energy, and in a second version by Energy and Environmental Analysis Inc. The micro-computer version was partially developed in 1985 by Battelle Pacific Northwest Laboratories, and completed and modified for the pulp and paper sector in B.C. at the Natural Resources Management Program at Simon Fraser University in 1987 and 1988. The model forecasts energy demand through a detailed exposition of the industrial processes, providing an assessment of the penetration of new technologies.[4]

The basic premise of ISTUM is that technology choices are aimed at minimizing total production costs. The technologies compete on the basis of life-cycle costs, including capital, fuel and maintenance costs. Each technology choice will penetrate gradually according to the requirement for new capital in each category determined by the retirement of old stock and demand for final products. ISTUM also provides the option of retrofitting or upgrading existing capital stock. By applying a capital retirement function and a host of conservation and energy management options, the capital stock is continually being replaced and modified by technologies that ensure the lowest production costs.[5]

Two energy price scenarios were run on the B.C. ISTUM model for the purposes of this study, forecasting explicitly the developments in energy intensities for the B.C. pulp and paper industry.

Footnotes

[1] GERAD's papers on specific industries will be referenced separately. For an introduction to the MARKAL model, see: D. Baillard-Haurie; C. Berger; A. Haurie and R. Loulou, Modelling Energy Technology Choices in Industry: The MARKAL Approach, Les Cahiers du GERARD, Ecoles des Hautes Etudies Commercials, Affilies a l'Universite de Montreal. (Montreal: GERAD, October 1987).

[2] G. Lafrance, "Presentation of the MEDEQ Model" (Varennes: INRS-Energie, February 1988).

[3] Electric Power Research Institute, Energy-Use Patterns and Indicators, vol. 1, Summary, EM5126, R.P. 19440 -16 (Palo Alto: EPRI, April 1987).

[4] Energy and Environmental Analysis Inc., Industrial Energy Productivity Project-Final Report, vol. 1 of 9, prepared under subcontract to Mellon Institute, under contract #DE-AC01-70CS-40151 from U.S. Department of Energy, reproduced by NTIS (Arlington: Energy and Environmental Analysis Inc., February 1983).

[5] M. Jaccard and F. Bohlken, Forecasting the Demand for Energy in the B.C. Pulp and Paper Sector Using the ISTUM Model, Paper prepared for B.C. Hydro and Power Authority (Burnaby: Simon Fraser University, Natural Resources Management Program, July 1988).

APPENDIX C

THE SERF MODEL

Appendix C

THE SERF MODEL

The construction of an adequate modelling framework for this study would be a formidable task. Fortunately, such a structural model already existed in the Socio-Economic Resource Framework (SERF) developed by the Structural Analysis Division of Statistics Canada and installed at the Waterloo Simulation Research Facility at University of Waterloo.[1] The model is available through ROBBERT Associates in Ottawa.

SERF is essentially a very large input-output based model with the capability to calculate time paths for variables. The model keeps track of stocks and flows of all materials in the economy as well as demographic developments. Because of the inclusion of dynamic relationships such as changes in size and composition of the population, capacity growth and resource availability, the model can be used to address questions of technological change and transition to alternate resources.

C.1 Components of SERF

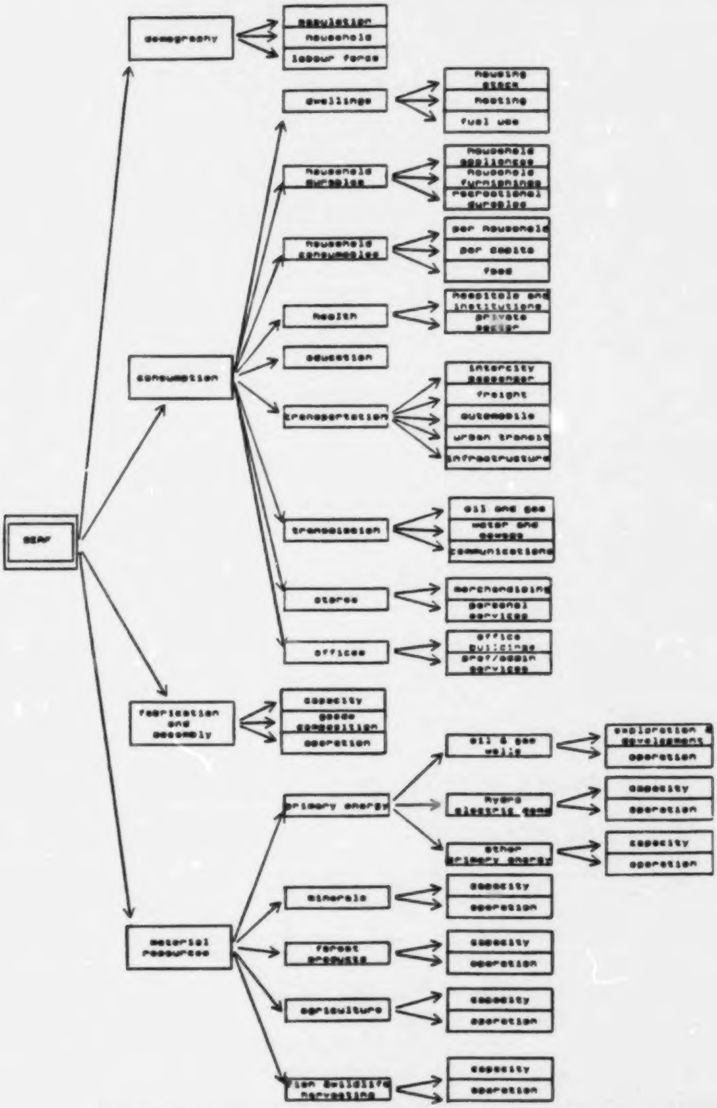
The physical transformation processes in SERF fall into four major groups: demography, consumption, fabrication and assembly, and material resources. Each of these have several subcomponents. This conceptual hierarchy of SERF is represented in Figure C.1. SERF is an analytical framework rather than a single model. Sub-models can be built and modified within SERF to serve specific purposes.

C.1.1 Demography

The demography component represents the basic demographic processes of population dynamics, household formation and labour force participation. It keeps track of population by age and sex, households and the availability of labour. The control variables reflect alternatives with respect to fertility, migration, household formation and labour force participation.

Figure C.1

SERF Conceptual Hierarchy


SERF
demography
population
household
labour force
consumption
dwellings
housing stock
heating
fuel use
household durables
household appliances
household furnishings
recreational durables
household consumables
per household
per capita
food
health
hospitals and institutions
private sector
education
transportation
intercity passenger
freight
automobile
urban transit
infrastructure
transmission
oil and gas
water and sewage
communications
stores
merchandising
personal services
offices
office buildings
prof/admin services
fabrication and assembly
capacity
goods composition
operation
material resources
primary energy
oil & gas wells
exploration & development
operation
hydro electric gens
capacity
operation
other primary energy
capacity
operation
minerals
capacity
operation
forest products
capacity
operation
agriculture
capacity
operation
fish &wildlife harvesting
capacity
operation

SOURCE: Waterloo Simulation Research Facility (WATSRF), University of Waterloo, Socio-Economic Resource Framework Reference Manual, Vol. 2 (Waterloo: WATSRF, 1988), p. v.

C.1.2 Consumption

The consumption component represents the infrastructure that provides the goods and services required by human society. It calculates the flow of goods, energy and labour required to generate and operate this infrastructure. It keeps track of dwellings, consumer goods, hospitals, schools, all forms of transportation, hotels, restaurants, stores, banks and cultural and recreational facilities. The control variables reflect decisions affecting the accessibility or use of consumer goods and infrastructure.

C.1.3 Fabrication and Assembly

The fabrication and assembly component represents the processes that transform materials into finished goods and primary energy into fuels. It keeps track of energy, labour, goods and productive capacity. Goods production is represented by an input-output model formulated in terms of approximately 500 goods and 150 processes. This component also keeps track of the exchange of domestically produced goods and materials for those produced in other countries. The control variables reflect decisions concerning capital investment and foreign trade, and changes in market shares and production technology.

C.1.4 Material Resources

The material resources component represents both renewable and non-renewable resources. It keeps track of the availability of non-renewable resources such as coal, oil, gas, metals and non-metallic minerals and the generation of electricity from hydro dams. The availability of the non-renewable resources is influenced by control variables which set activity levels for exploration, extraction and refining. Renewable resources such as livestock, crops, forests and fish are influenced by their natural dynamics as well as resource management and harvesting activities. Control variables reflect management and land use decisions.

C.2 The Data in SERF

The software system is capable of storing and manipulating multi-dimensional arrays. For example, the variable "population" may be broken down by sex, age, location and time. Thus the single variable population may contain a set of 2 (sexes) x 100 (age groups) x 10 (provinces) x 100 (years), i.e., 2 x 10^{15} values. Data manipulation is accomplished by operating on such multi-dimensional variables.

SERF has compiled data from a wide range of sources including: population censuses, household surveys, censuses of manufacturing and primary industries, transportation surveys, input-output tables and data from administrative records.

This data has been transformed, augmented and integrated. It is compiled at a disaggregated level to conform with the accounting relationship of stock-flow calculations and physical laws. The data are represented in physical units that are linked through physical processes.

C.3 Dependency Structure of Transformation Processes

The dependency structure of SERF is illustrated in Figure C.2. SERF is essentially a framework that combines over forty individual models in a consistent and comprehensive manner. Models can therefore be modified or added within this framework according to the questions analyzed. For example, the domestic demand for a commodity will be determined by the development of the population size and characteristics, and the resulting household formation, size and consumption patterns. If inconsistencies occur within a scenario, such as the demand for a product exceeding the ability to produce that commodity, given the available raw materials, labour and current capacity in the fabrication and assembly sector, the problem will be identified as a "tension."

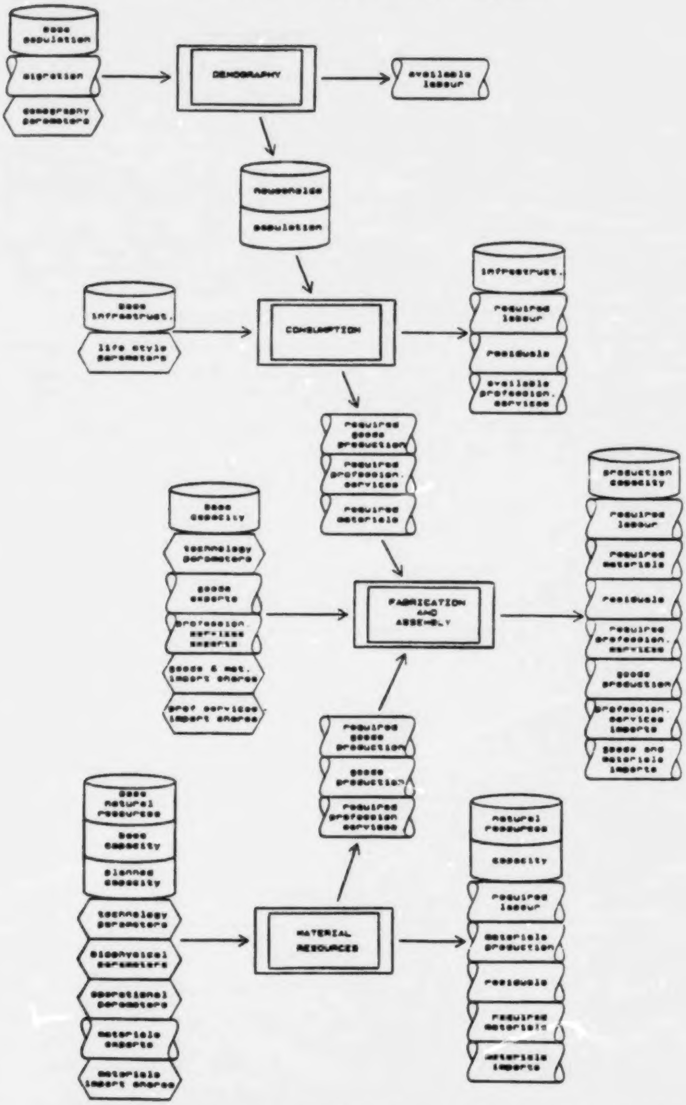
Such tensions can only be resolved by user interaction, adjusting input parameters to iteratively create a new internally consistent scenario. It is possible to specify an overlay routine which recalculates input variables as a function of output variables.

C.4 The Use of SERF in the Study

SERF traces the physical flows of materials, labour and energy required to meet the final demand for each product. Inter-industry requirements are taken into account through the input-output framework, forming a consistent picture of total demand. For the purpose of forecasting total demand for natural gas, a scenario was generated that specified the penetration of certain production technologies, with their respective energy intensity ratios. The regional process data were used to help specify these energy intensities for production processes incorporated within SERF. Multiplying total production from each industry by the energy intensities of production,

Figure C.2

SERF Overview Dependency Diagram


base population
migration
demography parameters
DEMOGRAPHY
available labour
households
population
base infrastruct.
life style parameters
CONSUMPTION
infrastruct.
required labour
residuals
available profession. services
required goods production
required profession. services
required materials
base capacity
technology parameters
goods exports
profession. services exports
goods & mat. import shares
prof services import shares
FABRICATION AND ASSEMBLY
production capacity
required labour
required materials
residuals
required profession. services
goods production
profession. services imports
goods and materials imports
required goods production
goods production
required profession services
base natural resources
base capacity
planned capacity
technology parameters
biophysical parameters
operational parameters
materials exports
materials import shares
MATERIAL RESOURCES
natural resources
capacity
required labour
materials production
residuals
required materials
materials imports

SOURCE: Waterloo Simulation Research Facility (WATSRF), University of Waterloo, Socio-Economic Resource Framework Reference Manual, Vol. 2 (Waterloo: WATSRF, 1988), p. vii.

generated energy demand by fuel for each industry and for the total industrial sector.

C.5 Limitations of the SERF Model

The classification of industries between the secondary manufacturing, or fabrication and assembly, sector and the primary sectors created some unexpected problems.

The chemical industries, petroleum refineries and cement are included in the fabrication and assembly component, which is broken down into three subcomponents: capacity formation, goods conversion and goods production. Primary metals and pulp and paper mills are classified under material resources.

Serious problems remain in ensuring consistent SERF results, as indicated by various shortcomings of this model were discovered as work progressed. SERF is designed primarily to produce the aggregate economic impact results, and although highly disaggregated sectors and commodities can be isolated, the categorization of industries in SERF proved difficult to work with.

While production in the secondary manufacturing (fabrication and assembly) sector is demand driven, based on household and industry consumption patterns, production in the primary sector is simply based on capacity assumptions. When capacity exceeds demand for these industries, production will still take place up to capacity, with excess products simply being stockpiled. This problem was also difficult to detect since capacity utilization, or load factor measures give no indication of any such imbalance.

Only some of the manufacturing industries reviewed in this study were classified as secondary industries, and the picture was further complicated in that those industries viewed as primary according to SERF, were also highly export oriented. For such export oriented industries, notably pulp and paper, capacity is clearly built to satisfy export demand. However, since some of these are viewed as primary industries, capacity is the driving variable in SERF.

For domestically oriented industries, exports are more realistically determined as production in excess of domestic demand and constrained by capacity. Petroleum refineries are an example of the latter. Where such industries are classified as secondary producers in SERF, export growth becomes inappropriate as a control variable.

While a reclassification of industries in SERF would be a monumental task, these problems of production forecasts can be solved if the user can modify initial runs in an iterative process until a satisfactory solution is found, balancing capacity and export variables against domestic consumption and production. The task is then reduced to one of identifying problem industries and isolating the variables involved. This requires a high degree of user interaction and understanding.

A major inconsistency remains in that SERF has matches the supply data from Statistics Canada's Quarterly Supply and Demand of Energy[2] which represents final end-use of energy, with demand data from Consumption of Purchased Fuels and Electricity,[3] which measures energy consumption in primary uses. If for example, natural gas is used to generate electricity in a chemical plant, this would appear as natural gas demand and electricity supply. The problem could not be resolved in the modelling work undertaken for this report.

Footnotes

[1] Waterloo Simulation Research Facility, Socio-Economic Resource Framework, Reference Manual, Version 2, vols. 1 and 2 (Waterloo: WATSRF, December 1988).

[2] Canada, Statistics Canada, Quarterly Report on Energy Supply/Demand in Canada, Catalogue No. 57-003, Quarterly (Ottawa: Statistics Canada, 1988).

[3] Canada, Statistics Canada, Consumption of Purchased Fuels and Electricity, Catalogue No. 57-208, Annual (Ottawa: Statistics Canada, 1975-1986).

APPENDIX D

RESULTS

TABLE D.1

ENERGY USE IN THE PULP AND PAPER INDUSTRY
BASE CASE
(terajoules)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	119 604.81	445.34	91 814.41	9 190.05	90 704.68	311 759.30
1983	122 632.16	466.62	98 397.23	9 432.31	94 333.20	325 261.52
1984	122 614.66	475.99	102 342.64	9 450.23	95 572.19	330 455.71
1985	120 898.05	478.03	104 468.94	9 346.42	95 386.88	330 578.32
1986	119 955.94	482.31	106 797.19	9 311.32	95 702.65	332 249.42
1987	119 362.53	487.24	108 966.06	9 312.29	96 196.02	334 324.14
1988	119 247.99	493.18	111 287.98	9 341.06	96 882.67	337 252.88
1989	119 792.12	500.94	113 943.53	9 412.15	97 915.19	341 563.93
1990	121 179.03	511.34	117 123.68	9 540.33	99 448.61	347 803.00
1991	123 163.59	523.38	120 600.29	9 706.34	101 280.88	355 274.48
1992	125 124.08	534.38	123 751.33	9 860.85	102 893.04	362 163.68
1993	126 633.17	543.55	126 502.60	9 979.77	104 134.00	367 793.10
1994	127 548.27	550.23	128 697.32	10 051.89	104 886.52	371 734.23
1995	127 939.44	554.69	130 389.43	10 082.72	105 208.20	374 174.48
1996	127 946.71	557.51	131 707.36	10 083.29	105 214.17	375 509.04
1997	127 710.59	559.27	132 785.56	10 064.69	105 020.01	376 140.11
1998	127 370.55	560.59	133 762.99	10 037.89	104 740.38	376 472.40
1999	127 064.00	562.05	134 782.17	10 013.73	104 488.30	376 910.24
2000	126 833.52	563.85	135 889.82	9 995.57	104 298.77	377 581.52
2001	126 650.80	565.86	137 057.82	9 981.17	104 148.51	378 404.16
2002	126 584.04	568.41	138 362.30	9 975.90	104 093.62	379 584.27
2003	126 553.55	571.13	139 719.22	9 973.50	104 068.54	380 885.94
2004	126 526.01	573.87	141 092.72	9 971.33	104 045.89	382 209.83
2005	126 509.19	576.68	142 491.78	9 970.01	104 032.06	383 579.72
2006	126 510.74	579.58	143 925.63	9 970.13	104 033.33	385 019.40
2007	126 540.68	582.63	145 406.53	9 972.49	104 057.96	386 560.29
2008	126 607.13	585.87	146 945.01	9 977.72	104 112.60	388 228.33
2009	126 697.29	589.23	148 527.53	9 984.83	104 186.74	389 985.62
2010	126 797.69	592.66	150 139.16	9 992.74	104 269.31	391 791.57
2011	126 901.43	596.13	151 772.17	10 000.92	104 354.61	393 625.25
2012	126 998.22	599.58	153 414.44	10 008.54	104 434.20	395 455.00
2013	127 077.08	602.97	155 052.52	10 014.76	104 499.05	397 246.38
2014	127 127.14	606.24	156 672.51	10 018.70	104 540.21	398 964.80
2015	127 137.76	609.33	158 260.33	10 019.54	104 548.94	400 575.91

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.2

ENERGY USE IN THE PULP AND PAPER INDUSTRY SENSITIVITY CASES

(terajoules)

	Fuel Oil		LPG		Electricity		Coal		Natural Gas		Total	
	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]
1982	119 604.81	119 604.81	445.34	445.34	91 814.41	91 814.41	9 190.05	9 190.05	90 704.68	90 704.68	311 759.30	311 759.30
1983	122 632.16	122 632.16	466.62	466.62	98 397.23	98 397.23	9 432.31	9 432.31	94 333.20	94 333.20	325 261.52	325 261.52
1984	122 614.66	122 614.66	475.99	475.99	102 342.64	102 342.64	9 450.23	9 450.23	95 572.19	95 572.19	330 455.71	330 455.71
1985	120 898.05	120 898.05	478.03	478.03	104 468.94	104 468.94	9 346.42	9 346.42	95 386.88	95 386.88	330 578.32	330 578.32
1986	122 030.46	118 596.34	482.51	476.85	105 447.46	105 586.73	9 433.96	9 205.79	96 280.34	94 617.95	333 674.73	328 483.65
1987	123 275.92	116 514.09	487.43	475.61	106 523.69	106 365.72	9 530.25	9 090.07	97 263.00	93 900.42	337 080.29	326 345.91
1988	124 779.76	115 010.56	493.38	475.66	107 823.16	107 333.42	9 646.51	9 009.13	98 449.50	93 439.99	341 192.31	325 268.75
1989	126 743.30	114 260.22	501.14	477.81	109 519.88	108 681.72	9 798.31	8 977.50	99 998.71	93 393.55	346 561.35	325 790.80
1990	129 375.07	114 442.55	511.55	482.92	111 794.01	110 612.65	10 001.76	9 009.96	102 075.14	93 920.16	353 757.53	328 468.24
1991	132 420.62	115 306.34	523.59	490.00	114 425.85	112 908.51	10 237.23	9 067.28	104 478.19	94 821.28	362 085.67	332 615.41
1992	135 204.67	116 232.34	534.60	496.41	116 831.42	114 957.14	10 452.44	9 160.10	106 674.62	95 581.11	369 697.75	336 427.10
1993	137 522.95	116 721.72	543.76	501.00	118 834.66	116 601.37	10 631.66	9 198.67	108 503.72	95 983.54	376 036.76	339 006.29
1994	139 212.81	116 634.37	550.45	503.14	120 294.88	117 685.10	10 762.30	9 191.78	109 836.99	95 911.71	380 657.43	339 926.11
1995	140 341.48	116 040.90	554.91	503.10	121 270.16	118 263.04	10 849.56	9 145.01	110 727.49	95 423.69	383 743.59	339 375.74
1996	141 054.71	115 081.81	557.73	501.45	121 886.47	118 464.34	10 904.70	9 069.43	111 290.22	94 635.01	385 693.83	337 752.04
1997	141 501.93	113 898.12	559.50	498.78	122 272.91	118 424.21	10 939.27	8 976.14	111 643.06	93 661.62	386 916.67	335 458.88
1998	141 834.33	112 629.73	560.81	495.71	122 560.15	118 282.36	10 964.97	8 876.19	111 905.33	92 618.60	387 825.59	332 902.59
1999	142 202.98	111 414.51	563.27	492.82	122 879.57	118 182.10	10 993.56	8 780.42	112 196.98	91 619.29	388 836.36	330 489.14
2000	142 659.35	110 295.49	564.07	490.33	123 273.05	118 170.92	11 028.75	8 692.23	112 556.25	90 699.06	390 081.47	328 348.04
2001	143 169.67	109 244.71	566.09	488.10	123 714.09	118 221.46	11 068.20	8 609.42	112 958.90	89 835.00	391 476.90	326 398.69
2002	143 813.27	108 331.13	568.64	486.45	124 270.17	118 411.02	11 117.96	8 537.42	113 466.66	89 083.74	393 236.70	324 849.76
2003	144 501.14	107 451.27	571.36	484.92	124 864.56	118 629.67	11 171.13	8 468.06	114 009.40	88 360.20	395 117.59	323 394.12
2004	145 195.67	106 571.70	574.10	483.37	125 464.71	118 841.11	11 224.83	8 398.76	114 557.38	87 636.91	397 016.69	321 931.85
2005	145 905.89	105 700.17	576.91	481.82	126 078.42	119 053.85	11 279.73	8 330.06	115 117.74	86 920.22	398 958.70	320 486.12
2006	146 640.90	104 844.21	579.82	480.32	126 713.54	119 276.56	11 336.56	8 262.62	115 697.64	86 216.34	400 968.70	319 080.07
2007	147 412.67	104 013.79	582.87	478.91	127 380.43	119 521.12	11 396.22	8 197.18	116 306.56	85 533.46	403 078.75	317 744.46
2008	148 251.23	103 216.96	586.10	477.61	128 067.76	119 797.48	11 459.50	8 134.36	116 952.39	84 878.20	405 316.99	316 504.63
2009	149 082.20	102 440.80	589.47	476.42	128 823.09	120 091.59	11 525.29	8 073.21	117 623.80	84 239.95	407 643.86	315 321.96
2010	149 950.09	101 671.82	592.90	475.22	129 573.05	120 388.02	11 592.38	8 012.61	118 308.55	83 607.60	410 016.97	314 155.26
2011	150 826.91	100 903.01	596.37	474.00	130 330.71	120 678.45	11 660.17	7 952.02	119 000.34	82 975.38	412 414.49	312 982.86
2012	151 700.45	100 124.01	599.82	472.70	131 085.54	120 950.27	11 727.70	7 890.63	119 689.56	82 334.79	414 803.07	311 772.40
2013	152 557.42	99 323.75	603.21	471.28	131 826.06	121 189.42	11 793.95	7 827.56	120 365.71	81 676.71	417 146.35	310 488.71
2014	153 384.45	98 491.30	606.48	469.68	132 540.69	121 381.47	11 857.89	7 761.95	121 018.21	80 992.15	419 407.72	309 096.55
2015	154 168.10	97 615.92	609.58	467.86	133 217.86	121 511.72	11 918.47	7 692.97	121 636.49	80 272.31	421 550.51	307 560.78

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

[a] Sensitivity case with unchanged energy intensities, reflecting no further conservation.

[b] Sensitivity case with unchanged export parameters, reflecting a stagnant manufacturing sector.

TABLE D.3

ENERGY USE IN THE IRON AND STEEL INDUSTRY
BASE CASE
(terajoules)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	19 664.52	303.43	30 759.80	117.51	62 405.42	113 250.67
1983	19 608.39	309.73	31 236.51	118.61	63 054.43	114 327.32
1984	19 570.69	314.76	31 684.94	119.47	63 638.89	115 328.75
1985	19 566.07	319.80	32 128.15	120.17	64 205.78	116 339.97
1986	19 608.06	324.71	32 588.59	120.80	64 799.98	117 442.15
1987	19 709.70	329.69	33 088.37	121.42	65 464.77	118 713.95
1988	19 843.47	334.94	33 615.49	122.00	66 108.63	120 024.54
1989	20 004.06	340.38	34 160.83	122.49	66 710.82	121 338.58
1990	20 183.42	345.85	34 710.08	122.84	67 241.16	122 603.36
1991	20 380.94	351.34	35 261.33	123.05	67 694.28	123 810.94
1992	20 596.08	356.83	35 812.60	123.09	68 065.08	124 953.69
1993	20 817.90	362.31	36 343.76	123.17	68 383.50	126 030.63
1994	21 045.63	367.74	36 851.99	123.27	68 645.68	127 034.30
1995	21 278.49	373.12	37 334.53	123.38	68 848.03	127 957.55
1996	21 515.74	378.41	37 788.66	123.51	68 987.24	128 793.55
1997	21 756.60	383.61	38 211.69	123.64	69 060.19	129 535.73
1998	22 000.31	388.68	38 601.02	123.77	69 064.08	130 177.85
1999	22 246.10	393.61	38 954.08	123.90	68 996.37	130 714.06
2000	22 493.18	398.38	39 268.45	124.02	68 854.86	131 138.90
2001	22 740.74	402.97	39 541.76	124.13	68 637.62	131 447.21
2002	22 989.98	407.39	39 775.27	124.24	68 349.05	131 645.93
2003	23 233.73	411.71	39 996.01	124.30	68 037.62	131 803.36
2004	23 472.31	415.93	40 204.67	124.32	67 705.22	131 922.45
2005	23 705.60	420.07	40 401.25	124.30	67 352.47	132 003.69
2006	23 933.52	424.11	40 585.75	124.24	66 980.05	132 047.67
2007	24 155.94	428.05	40 758.10	124.14	66 588.47	132 054.71
2008	24 372.74	431.89	40 918.30	124.00	66 178.32	132 025.25
2009	24 583.79	435.63	41 066.24	123.82	65 750.08	131 959.56
2010	24 788.93	439.26	41 201.88	123.61	65 304.26	131 857.94
2011	24 988.02	442.79	41 325.12	123.35	64 841.30	131 720.58
2012	25 180.89	446.21	41 435.88	123.06	64 361.67	131 547.71
2013	25 367.39	449.52	41 534.05	122.74	63 865.77	131 339.45
2014	25 547.33	452.70	41 619.52	122.37	63 354.02	131 095.95
2015	25 720.54	455.77	41 692.20	121.97	62 826.80	130 817.28

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.4

ENERGY USE IN THE IRON AND STEEL INDUSTRY SENSITIVITY CASES (terajoules)

	Fuel Oil		LPG		Electricity		Coal		Natural Gas		Total	
	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]
1982	19 664.52	19 664.52	303.43	303.43	30 759.80	30 759.80	117.51	117.51	62 405.42	62 405.42	113 250.67	113 250.67
1983	19 608.39	19 608.39	309.37	309.37	31 236.51	31 236.51	118.61	118.61	63 054.43	63 054.43	114 327.32	114 327.32
1984	19 570.69	19 570.69	314.76	314.76	31 684.94	31 684.94	119.47	119.47	63 638.89	63 638.89	115 328.75	115 328.75
1985	19 566.07	19 566.07	319.80	319.80	32 128.15	32 128.15	120.17	120.17	64 205.78	64 205.78	116 339.97	116 339.97
1986	19 868.34	19 465.90	324.71	322.36	32 621.21	32 352.30	122.02	119.92	65 191.12	64 330.14	118 125.40	116 590.62
1987	20 171.01	19 424.26	329.69	324.92	33 121.49	32 609.19	123.89	119.66	66 190.89	64 516.73	119 936.96	116 904.76
1988	20 482.35	19 419.30	334.94	327.78	33 649.14	32 896.94	125.86	119.39	67 245.36	64 695.51	121 847.66	117 468.93
1989	20 824.79	19 445.63	340.38	330.87	34 195.02	33 207.19	127.90	119.07	68 336.26	64 848.52	123 834.35	117 961.28
1990	21 159.62	19 496.16	345.85	334.06	34 744.83	33 526.46	129.96	118.65	69 435.01	64 948.22	125 815.27	118 422.55
1991	21 496.67	19 567.27	351.34	337.31	35 296.63	33 853.56	132.02	118.13	70 537.75	64 991.70	127 813.41	118 868.00
1992	21 831.73	19 661.37	356.83	340.64	35 848.45	34 187.33	134.09	117.51	71 640.53	64 976.09	129 811.63	119 282.94
1993	22 166.61	19 760.78	362.31	343.91	36 396.34	34 496.25	136.14	116.92	72 739.43	64 911.08	131 802.83	119 630.89
1994	22 499.09	19 864.56	367.74	347.10	36 944.28	34 783.88	138.19	116.36	73 830.45	64 793.32	133 779.74	119 905.23
1995	22 827.93	19 971.76	373.12	350.20	37 484.25	35 041.78	140.20	115.80	74 909.55	64 620.00	135 735.06	120 089.54
1996	23 151.91	20 081.43	378.41	353.19	38 016.23	35 269.55	142.19	115.27	75 972.67	64 388.34	137 661.42	120 207.76
1997	23 469.76	20 192.63	383.61	356.03	38 536.16	35 464.85	144.15	114.76	77 015.71	64 095.81	139 551.39	120 234.06
1998	23 780.33	20 304.38	388.68	358.73	39 047.95	35 625.40	146.05	114.22	78 034.49	63 740.17	141 397.40	120 142.90
1999	24 082.03	20 415.71	393.61	361.23	39 543.61	35 748.97	147.91	113.70	79 024.83	63 319.41	143 191.88	119 959.02
2000	24 373.87	20 525.59	398.38	363.54	40 022.73	35 833.46	149.70	113.17	79 982.51	62 831.81	144 937.19	119 667.56
2001	24 654.45	20 633.00	402.97	365.62	40 483.46	35 876.81	151.42	112.62	80 903.25	62 275.91	146 596.55	119 263.96
2002	24 934.67	20 736.88	407.39	367.50	40 927.17	35 880.62	153.06	112.07	81 789.97	61 656.55	148 202.26	118 756.63
2003	25 196.95	20 835.31	411.71	369.21	41 361.10	35 867.21	154.71	111.47	82 657.15	61 014.09	149 773.60	118 197.38
2004	25 447.89	20 922.49	415.93	370.75	41 785.82	35 837.20	156.29	110.81	83 506.91	60 350.34	151 311.55	117 591.59
2005	25 700.51	21 000.19	420.07	372.13	42 201.13	35 790.44	157.85	110.11	84 326.89	59 665.85	152 815.45	116 936.73
2006	25 947.62	21 068.21	424.11	373.33	42 606.86	35 726.83	159.37	109.36	85 146.76	58 961.22	154 284.73	116 236.97
2007	26 188.75	21 126.28	428.05	374.36	43 002.83	35 646.18	160.86	108.57	85 938.04	58 236.88	155 718.63	115 492.36
2008	26 423.80	21 174.16	431.89	375.21	43 388.79	35 548.33	162.29	107.73	86 709.34	57 493.33	157 116.11	114 698.76
2009	26 652.60	21 211.57	435.63	375.87	43 764.49	35 433.09	163.70	106.84	87 460.15	56 730.99	158 476.56	113 868.36
2010	26 876.01	21 238.34	439.26	376.35	44 129.69	35 300.25	165.06	105.90	88 189.96	55 950.28	159 799.00	112 971.02
2011	27 090.85	21 253.87	442.79	376.62	44 484.11	35 149.59	166.39	104.92	88 898.25	55 151.57	161 082.26	112 036.57
2012	27 299.96	21 256.15	446.21	376.70	44 827.47	34 980.88	167.67	103.89	89 584.44	54 335.94	162 325.74	111 054.88
2013	27 502.14	21 250.76	449.53	376.57	45 159.47	34 793.80	168.91	102.82	90 247.92	53 501.61	163 527.97	110 026.66
2014	27 697.23	21 231.36	452.70	376.22	45 479.81	34 588.35	170.11	101.70	90 886.09	52 651.04	164 687.94	108 948.70
2015	27 885.02	21 199.67	455.77	375.66	45 788.16	34 364.01	171.26	100.53	91 504.31	51 783.82	165 804.53	107 823.69

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

[a] Sensitivity case with unchanged energy intensities, reflecting no further conservation.
[b] Sensitivity case with unchanged expert parameters, reflecting a stagnant manufacturing sector.

TABLE D.5

ENERGY USE IN PETROLEUM REFINERIES
BASE CASE
(terajoules)

Year	Fuel Oil	LPG	Electricity	Natural Gas	Total
1982	70.02	2.20	12 374.83	43 355.93	55 802.99
1983	67.93	2.18	12 126.53	42 485.97	54 682.60
1984	66.23	2.17	11 945.12	41 850.40	53 863.92
1985	64.45	2.15	11 742.15	41 139.29	52 948.05
1986	63.22	2.15	11 635.97	40 767.27	52 468.61
1987	62.12	2.16	11 549.34	40 463.78	52 077.39
1988	61.13	2.16	11 482.07	40 187.52	51 732.88
1989	60.22	2.16	11 424.94	39 907.13	51 394.45
1990	59.30	2.15	11 365.67	39 580.52	51 007.64
1991	58.85	2.15	11 393.30	39 517.69	50 971.99
1992	58.40	2.14	11 419.11	39 409.18	50 888.84
1993	57.76	2.13	11 403.49	39 158.49	50 621.86
1994	57.25	2.12	11 405.74	38 970.38	50 435.49
1995	56.89	2.11	11 431.40	38 862.79	50 353.20
1996	56.56	2.11	11 456.53	38 753.46	50 268.66
1997	56.33	2.10	11 495.36	38 690.38	50 244.18
1998	56.12	2.10	11 534.12	38 626.76	50 219.11
1999	56.06	2.10	11 596.12	38 640.22	50 294.51
2000	56.17	2.11	11 688.27	38 752.52	50 499.06
2001	56.28	2.11	11 777.48	38 853.06	50 688.94
2002	56.41	2.12	11 862.55	38 938.04	50 859.12
2003	56.44	2.12	11 929.88	38 963.25	50 951.70
2004	56.58	2.12	12 018.82	39 057.45	51 134.97
2005	56.68	2.13	12 100.48	39 126.20	51 285.49
2006	56.79	2.13	12 185.74	39 204.90	51 449.56
2007	56.96	2.14	12 284.08	39 323.67	51 666.85
2008	57.27	2.15	12 412.12	39 534.88	52 006.42
2009	57.46	2.16	12 515.75	39 665.66	52 241.03
2010	57.92	2.18	12 680.37	39 986.43	52 726.90
2011	58.26	2.19	12 817.37	40 216.35	53 094.16
2012	58.34	2.19	12 899.26	40 270.93	53 230.71
2013	58.81	2.21	13 069.96	40 599.83	53 730.81
2014	58.89	2.21	13 152.94	40 653.31	53 867.36
2015	59.17	2.22	13 281.09	40 844.13	54 186.61

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.6

ENERGY USE IN PETROLEUM REFINERIES
SENSITIVITY CASES
(terajoules)

	Fuel Oil		LPG		Electricity		Natural Gas		Total	
	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]
1982	70.07	70.02	2.20	2.20	12 382.54	12 374.96	43 382.93	43 356.35	55 837.73	55 803.53
1983	68.01	67.93	2.18	2.18	12 141.26	12 126.68	42 537.59	42 486.05	54 749.04	54 683.28
1984	66.34	66.23	2.17	2.17	11 964.09	11 945.27	41 916.88	41 850.93	53 949.48	53 864.60
1985	64.55	64.45	2.15	2.15	11 759.78	11 742.31	41 201.06	41 139.83	53 027.54	52 948.74
1986	64.71	62.71	2.16	2.13	11 789.65	11 541.23	41 305.71	40 435.36	53 162.23	52 041.43
1987	64.96	61.20	2.17	2.13	11 834.91	11 379.49	41 464.26	39 868.68	53 366.29	51 311.50
1988	64.86	59.86	2.16	2.12	11 816.51	11 243.38	41 399.80	39 352.09	53 283.34	50 657.45
1989	65.10	58.70	2.17	2.10	11 860.19	11 136.52	41 552.84	38 899.67	53 480.30	50 097.00
1990	65.59	57.37	2.19	2.08	11 949.60	10 995.28	41 866.10	38 290.65	53 883.48	49 345.39
1991	65.93	56.63	2.20	2.07	12 011.39	10 962.63	42 082.60	38 023.93	54 162.12	49 045.26
1992	66.05	55.90	2.20	2.05	12 033.03	10 930.97	42 158.39	37 724.54	54 259.67	48 713.47
1993	65.91	55.00	2.20	2.03	12 008.59	10 857.22	42 072.76	37 282.66	54 149.46	48 196.91
1994	65.85	54.30	2.20	2.01	11 996.53	10 818.06	42 030.51	36 962.45	54 095.08	47 836.83
1995	65.91	53.85	2.20	2.00	12 008.74	10 820.41	42 073.29	36 785.62	54 150.14	47 661.89
1996	66.03	53.44	2.20	1.99	12 029.68	10 824.10	42 146.64	36 614.19	54 244.55	47 493.73
1997	66.24	53.10	2.21	1.98	12 068.48	10 836.50	42 282.60	36 472.83	54 419.54	47 364.41
1998	66.57	52.71	2.22	1.97	12 127.88	10 832.30	42 490.70	36 276.41	54 687.36	47 163.39
1999	66.99	52.51	2.23	1.97	12 205.16	10 861.31	42 761.45	36 191.70	55 035.84	47 107.49
2000	67.57	52.47	2.25	1.97	12 310.68	10 918.87	43 131.14	36 201.58	55 511.64	47 174.89
2001	68.17	52.45	2.27	1.97	12 419.99	10 975.40	43 514.14	36 207.07	56 004.57	47 236.89
2002	68.70	52.41	2.29	1.97	12 515.81	11 021.72	43 849.85	36 178.08	56 436.65	47 254.18
2003	69.08	52.26	2.30	1.96	12 585.14	11 044.87	44 092.76	36 072.77	56 749.29	47 171.85
2004	69.62	52.20	2.32	1.96	12 683.99	11 089.26	44 439.08	36 036.66	57 195.01	47 180.08
2005	70.13	52.11	2.34	1.96	12 776.51	11 124.59	44 763.21	35 970.74	57 612.19	47 149.40
2006	70.62	52.02	2.36	1.95	12 865.92	11 161.50	45 076.48	35 909.63	58 015.38	47 125.10
2007	71.16	51.96	2.37	1.95	12 965.18	11 205.35	45 424.25	35 870.46	58 462.97	47 129.73
2008	71.81	51.99	2.40	1.95	13 083.67	11 268.72	45 839.38	35 892.95	58 997.26	47 215.62
2009	72.27	51.90	2.41	1.95	13 166.63	11 305.17	46 130.04	35 829.01	59 371.35	47 188.03
2010	73.08	52.08	2.44	1.96	13 313.51	11 401.18	46 644.64	35 952.63	60 033.66	47 407.85
2011	73.79	52.16	2.46	1.96	13 443.74	11 475.28	47 100.89	36 005.35	60 620.88	47 534.75
2012	74.20	51.98	2.47	1.95	13 518.01	11 493.16	47 361.12	35 881.15	60 955.80	47 428.25
2013	75.13	52.19	2.51	1.96	13 686.94	11 599.19	47 952.98	36 031.11	61 717.56	47 684.46
2014	75.61	52.00	2.52	1.95	13 775.78	11 613.83	48 264.22	35 896.19	62 118.14	47 563.97
2015	76.36	52.00	2.55	1.95	13 911.68	11 672.61	48 740.35	35 897.50	62 730.94	47 624.07

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989

[a] Sensitivity case with unchanged energy intensities, reflecting no further conservation.
[b] Sensitivity case with unchanged export parameters, reflecting a stagnant manufacturing sector.

TABLE D.7

ENERGY USE FOR INDUSTRIAL CHEMICALS PRODUCTION
BASE CASE
(terajoules)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	22 006.09	246.79	38 998.53	1 011.22	133 760.37	196 022.99
1983	21 844.45	246.21	39 062.15	1 013.88	133 444.78	195 611.40
1984	22 448.45	254.29	40 465.08	1 052.38	137 824.03	202 044.24
1985	22 655.04	257.92	41 124.76	1 072.74	139 791.32	204 901.77
1986	22 998.89	263.15	42 000.68	1 099.97	142 626.16	208 988.85
1987	23 356.45	268.58	42 868.01	1 128.30	145 571.43	213 192.77
1988	23 709.50	273.74	43 647.05	1 154.55	148 216.90	217 001.74
1989	24 086.36	278.93	44 385.30	1 179.96	150 723.86	220 654.40
1990	24 484.34	284.10	45 073.47	1 204.27	153 060.74	224 106.92
1991	24 882.56	289.01	45 669.01	1 226.30	155 083.07	227 149.95
1992	25 264.31	293.45	46 137.81	1 245.12	156 675.01	229 615.69
1993	25 605.58	297.41	46 527.23	1 261.31	157 918.02	231 609.55
1994	25 982.42	301.79	46 975.92	1 278.59	159 280.67	233 819.38
1995	26 397.91	306.61	47 488.48	1 297.09	160 775.86	236 265.94
1996	26 785.29	311.11	47 944.43	1 313.49	161 993.23	238 347.55
1997	27 168.15	315.56	48 386.60	1 328.93	163 076.46	240 275.70
1998	27 540.28	319.88	48 804.10	1 343.09	163 987.64	241 995.00
1999	27 925.16	324.35	49 238.72	1 357.10	164 866.04	243 711.37
2000	28 362.45	329.43	49 759.71	1 372.83	165 940.68	245 765.10
2001	28 789.73	334.39	50 256.80	1 387.25	166 840.40	247 608.57
2002	29 172.79	338.84	50 670.87	1 398.68	167 369.72	248 950.90
2003	29 494.28	342.58	50 973.12	1 407.02	167 521.97	249 738.96
2004	29 912.47	347.43	51 437.37	1 419.83	168 198.26	251 315.36
2005	30 299.46	351.93	51 842.32	1 431.01	168 670.58	252 595.30
2006	30 695.65	356.53	52 257.60	1 442.47	169 167.32	253 919.57
2007	31 122.03	361.48	52 718.57	1 455.20	169 801.98	255 459.26
2008	31 580.41	366.81	53 227.57	1 469.25	170 579.89	257 223.93
2009	31 935.52	370.93	53 556.97	1 478.34	170 773.04	258 114.80
2010	32 462.70	377.06	54 168.85	1 495.23	171 856.16	260 360.00
2011	32 861.63	381.69	54 560.35	1 506.04	172 228.38	261 538.08
2012	33 172.09	385.30	54 800.44	1 512.66	172 116.99	261 987.47
2013	33 761.21	392.14	55 494.79	1 531.83	173 421.97	264 601.95
2014	34 059.11	395.60	55 704.54	1 537.62	173 202.64	264 899.50
2015	34 581.97	401.67	56 276.88	1 553.42	174 102.94	266 916.88

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.8

ENERGY USE FOR INDUSTRIAL CHEMICALS PRODUCTION
SENSITIVITY CASES
(terajoules)

	Fuel Oil		LPG		Electricity		Coal		Natural Gas		Total	
	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]
1982	22 006.09	22 006.23	246.79	246.79	38 998.53	38 998.78	1 011.22	1 011.22	133 760.37	133 761.22	196 022.99	196 024.25
1983	21 844.39	21 844.58	246.21	246.21	39 062.15	39 062.48	1 013.88	1 013.89	133 444.78	133 445.93	195 611.40	195 613.08
1984	22 446.45	22 446.65	254.29	254.29	40 465.08	40 465.42	1 052.38	1 052.39	137 824.03	137 825.21	202 044.24	202 045.96
1985	22 656.04	22 656.23	257.92	257.92	41 124.76	41 125.10	1 072.74	1 072.75	139 791.32	139 792.50	204 901.77	204 930.50
1986	23 114.46	22 606.64	263.15	258.68	41 956.73	41 288.00	1 094.50	1 061.31	142 626.16	140 206.04	209 056.99	205 442.67
1987	23 591.78	22 628.96	268.58	260.22	42 826.19	41 532.81	1 117.10	1 083.16	145 571.43	141 037.34	213 374.06	206 552.50
1988	24 044.56	22 712.64	273.74	262.23	43 647.10	41 811.93	1 138.54	1 106.01	148 365.26	141 985.18	217 469.20	207 877.98
1989	24 500.25	22 832.14	278.93	264.40	44 474.29	42 074.07	1 160.12	1 118.52	151 177.06	142 875.37	221 590.66	209 164.50
1990	24 954.98	22 906.56	284.10	265.80	45 299.74	42 169.46	1 181.65	1 126.66	153 962.94	143 199.31	225 708.41	209 668.11
1991	25 386.24	23 011.74	289.01	267.28	46 082.60	42 235.33	1 202.07	1 134.10	156 644.03	143 422.95	229 608.96	210 071.40
1992	25 775.72	23 104.69	293.45	268.36	46 789.60	42 193.69	1 220.51	1 138.66	159 047.25	143 282.24	233 126.53	209 987.86
1993	26 123.90	23 153.47	297.41	268.93	47 421.63	42 071.57	1 237.00	1 140.52	161 196.66	142 795.07	236 275.59	209 429.55
1994	26 506.36	23 250.47	301.79	270.06	48 119.54	42 036.59	1 255.20	1 144.15	163 567.99	142 532.96	239 752.89	209 234.33
1995	26 932.26	23 391.90	306.61	271.70	48 889.02	42 080.83	1 275.27	1 149.38	166 153.62	142 467.83	243 566.79	209 361.63
1996	27 327.48	23 504.80	311.11	273.01	49 606.45	42 072.50	1 293.99	1 152.62	168 622.30	142 153.35	247 161.33	209 156.29
1997	27 718.10	23 606.80	315.56	274.18	50 315.52	42 042.03	1 312.49	1 154.68	171 032.60	141 688.48	250 894.27	208 770.17
1998	28 097.76	23 657.00	319.88	274.78	51 004.70	41 922.54	1 330.46	1 152.71	173 375.24	140 864.77	254 128.04	207 672.80
1999	28 490.43	23 735.18	324.35	275.69	51 717.51	41 850.78	1 349.06	1 153.47	175 798.30	140 129.00	257 679.84	207 144.13
2000	28 936.57	23 863.00	329.43	277.17	52 527.36	41 865.78	1 370.18	1 155.05	178 551.06	139 615.70	261 714.59	206 776.71
2001	29 372.50	23 979.56	334.39	278.52	53 318.68	41 859.92	1 390.83	1 155.47	181 240.93	138 964.82	265 657.33	206 238.29
2002	29 763.22	24 049.37	338.84	279.23	54 028.12	41 771.86	1 409.33	1 153.04	183 652.46	137 975.71	269 192.08	205 229.23
2003	30 091.31	24 060.01	342.58	279.34	54 623.51	41 564.13	1 424.86	1 147.30	186 676.30	136 599.58	272 158.05	203 640.36
2004	30 517.96	24 141.77	347.43	280.41	55 398.00	41 514.10	1 445.06	1 145.92	188 306.94	135 749.55	276 017.40	202 831.75
2005	30 912.79	24 193.40	351.93	281.01	56 114.71	41 394.87	1 463.76	1 142.63	190 745.20	134 679.46	279 598.38	201 691.37
2006	31 317.00	24 244.05	356.53	281.60	56 848.45	41 274.12	1 482.90	1 139.30	193 239.33	133 611.61	282 344.20	200 550.86
2007	31 752.01	24 317.33	361.48	282.45	57 636.11	41 191.88	1 503.50	1 137.03	195 923.56	132 676.50	287 178.66	199 604.16
2008	32 219.67	24 417.08	366.81	283.61	58 487.04	41 154.00	1 525.64	1 135.98	198 809.23	131 867.41	291 406.38	198 876.06
2009	32 581.97	24 406.92	370.93	283.46	59 144.71	40 929.57	1 542.80	1 129.78	201 044.78	130 509.00	294 665.19	197 257.75
2010	33 119.83	24 562.01	377.06	285.29	60 121.05	40 985.38	1 568.26	1 131.33	204 362.53	130 030.36	299 549.72	196 994.27
2011	33 536.82	24 586.42	381.69	285.56	60 859.85	40 819.32	1 587.54	1 126.74	206 874.88	128 852.64	303 230.78	195 659.66
2012	33 843.57	24 511.87	385.30	284.71	61 434.84	40 493.71	1 602.53	1 117.75	208 829.38	127 182.48	306 096.62	193 590.53
2013	34 444.62	24 714.59	392.14	287.06	62 526.89	40 624.47	1 630.99	1 121.36	212 536.00	126 951.96	311 531.74	193 699.46
2014	34 748.64	24 610.80	395.60	285.86	63 077.59	40 251.59	1 645.39	1 111.07	214 413.44	125 154.06	314 250.56	191 413.96
2015	35 281.99	24 728.55	401.67	287.22	64 045.93	40 241.94	1 670.64	1 110.80	217 705.01	124 495.90	319 105.34	190 864.43

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

[a] Sensitivity case with unchanged energy intensities, reflecting no further conservation.
[b] Sensitivity case with unchanged export parameters, reflecting a stagnant manufacturing sector.

TABLE D.9

ENERGY USE IN THE MIXED FERTILIZER INDUSTRY
BASE CASE
(terajoules)

Year	Fuel Oil	LPG	Electricity	Natural Gas	Total
1982	44.74	26.75	359.03	147.19	577.71
1983	45.08	27.23	360.32	147.72	580.34
1984	45.49	27.75	362.47	148.60	584.30
1985	45.87	28.26	364.77	149.54	588.44
1986	46.23	28.78	367.30	150.59	592.90
1987	46.58	29.29	370.11	151.73	597.72
1988	46.96	29.83	373.49	153.12	603.41
1989	47.51	30.48	378.56	155.20	611.74
1990	48.35	31.33	386.42	158.42	624.52
1991	49.04	32.10	393.52	161.33	635.99
1992	49.59	32.79	399.98	163.98	646.34
1993	50.03	33.41	405.57	166.27	655.28
1994	50.37	33.98	410.40	168.25	663.00
1995	50.63	34.50	414.56	169.96	669.65
1996	50.81	34.97	418.17	171.44	675.40
1997	50.95	35.42	421.40	172.76	680.52
1998	51.30	36.02	426.45	174.84	688.61
1999	51.62	36.62	431.33	176.83	696.40
2000	51.92	37.20	436.03	178.76	703.91
2001	52.19	37.78	440.52	180.60	711.09
2002	52.44	38.33	444.79	182.35	717.91
2003	52.67	38.89	448.99	184.08	724.62
2004	52.89	39.45	453.15	185.78	731.27
2005	53.10	40.01	457.28	187.47	737.86
2006	53.30	40.57	461.36	189.15	744.38
2007	53.50	41.13	465.42	190.81	750.86
2008	53.69	41.69	469.44	192.46	757.29
2009	53.88	42.26	473.43	194.09	763.66
2010	54.06	42.83	477.40	195.72	770.01
2011	54.23	43.40	481.34	197.34	776.30
2012	54.39	43.97	485.22	198.93	782.51
2013	54.55	44.54	489.08	200.51	788.67
2014	54.70	45.11	492.89	202.07	794.77
2015	54.84	45.69	496.70	203.63	800.86

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.10

ENERGY USE IN THE MIXED FERTILIZER INDUSTRY SENSITIVITY CASES

(terajoules)

	Fuel Oil		LPG		Electricity		Natural Gas		Total	
	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]
1982	44.74	44.74	26.75	26.75	359.03	359.03	147.19	147.19	577.71	577.71
1983	45.08	45.08	27.23	27.23	360.32	360.32	147.72	147.72	580.34	580.34
1984	45.49	45.49	27.75	27.75	362.47	362.47	148.60	148.60	584.30	584.30
1985	45.87	45.87	28.26	28.26	364.77	364.77	149.54	149.54	588.44	588.44
1986	46.70	45.51	28.78	28.33	371.39	361.58	152.26	148.24	599.13	583.66
1987	47.53	45.39	29.29	28.54	378.00	360.65	154.97	147.86	609.80	582.44
1988	48.40	46.61	29.83	29.60	384.93	370.70	157.81	151.98	620.97	598.90
1989	49.45	47.66	30.48	30.58	393.30	379.83	161.24	155.72	634.47	613.80
1990	50.84	48.56	31.33	31.46	404.30	388.11	165.75	159.11	652.21	627.24
1991	52.08	49.30	32.10	32.27	414.21	395.66	169.81	162.21	668.20	639.45
1992	53.20	49.92	32.79	33.00	423.12	402.62	173.47	165.07	682.58	650.61
1993	54.22	50.42	33.41	33.67	431.19	408.71	176.78	167.56	695.60	660.36
1994	55.14	50.82	33.98	34.28	438.51	414.02	179.78	169.74	707.41	668.86
1995	55.98	51.13	34.50	34.84	445.19	418.66	182.52	171.64	718.18	676.27
1996	56.75	51.37	34.97	35.35	451.32	422.74	185.03	173.31	728.08	682.77
1997	57.48	51.54	35.42	35.83	457.09	426.35	187.40	174.79	737.38	688.51
1998	58.46	51.67	36.02	36.29	464.90	429.59	190.60	176.12	749.98	693.67
1999	59.42	51.77	36.62	36.72	472.58	432.56	193.74	177.34	762.36	698.40
2000	60.37	51.84	37.20	37.15	480.12	435.37	196.84	178.49	774.53	702.85
2001	61.30	51.91	37.78	37.57	487.51	438.10	199.87	179.61	786.45	707.18
2002	62.21	51.96	38.33	37.99	494.71	440.77	202.82	180.71	798.07	711.43
2003	63.11	52.01	38.89	38.40	501.89	443.39	205.76	181.78	809.65	715.58
2004	64.01	52.05	39.45	38.83	509.09	446.01	208.71	182.85	821.26	719.75
2005	64.92	52.10	40.01	39.26	516.30	448.71	211.67	183.96	832.90	724.03
2006	65.83	52.17	40.57	39.70	523.53	451.53	214.64	185.12	844.57	728.52
2007	66.74	52.25	41.13	40.17	530.79	454.55	217.61	186.35	856.27	733.32
2008	67.66	52.36	41.69	40.66	538.07	457.82	220.59	187.69	868.01	738.54
2009	68.58	52.48	42.26	41.16	545.37	461.16	223.59	189.06	879.79	743.87
2010	69.50	52.58	42.83	41.66	552.70	464.38	226.59	190.39	891.62	749.01
2011	70.42	52.67	43.40	42.15	560.06	467.50	229.61	191.66	903.49	753.98
2012	71.35	52.74	43.97	42.63	567.42	470.51	232.63	192.90	915.36	758.78
2013	72.28	52.80	44.54	43.11	574.80	473.41	235.65	194.08	927.27	763.40
2014	73.21	52.84	45.11	43.58	582.19	476.19	238.69	195.23	939.20	767.85
2015	74.14	52.87	45.69	44.05	589.64	478.87	241.74	196.23	951.21	772.12

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

[a] Sensitivity case with unchanged energy intensities, reflecting no further conservation.
[b] Sensitivity case with unchanged export parameters, reflecting a stagnant manufacturing sector.

TABLE D.11

ENERGY USE IN THE CEMENT INDUSTRY
BASE CASE
(terajoules)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	6 281.35	7.90	3 999.07	11 153.79	16 837.71	38 279.82
1983	5 929.07	7.57	3 843.69	10 966.03	15 845.04	36 591.40
1984	6 004.40	7.76	3 955.63	11 521.67	16 030.09	37 519.55
1985	6 072.22	7.95	4 056.99	12 040.99	16 227.56	38 405.71
1986	6 666.94	8.82	4 508.39	13 607.95	17 870.96	42 663.06
1987	7 302.30	9.76	4 987.92	15 281.17	19 672.92	47 254.07
1988	7 660.25	10.32	5 269.34	16 337.27	20 678.87	49 956.05
1989	7 959.93	10.79	5 497.52	17 198.43	21 466.24	52 132.90
1990	8 089.23	11.01	5 592.43	17 600.63	21 727.32	53 020.62
1991	8 138.87	11.10	5 615.47	17 726.40	21 707.33	53 199.17
1992	8 140.33	11.10	5 588.40	17 640.93	21 494.11	52 874.87
1993	8 077.57	11.02	5 517.59	17 408.65	21 125.78	52 140.60
1994	8 172.51	11.14	5 554.52	17 507.57	21 181.70	52 427.44
1995	8 372.00	11.42	5 661.66	17 818.36	21 514.32	53 377.76
1996	8 433.93	11.50	5 675.02	17 824.51	21 500.07	53 445.03
1997	8 471.33	11.55	5 671.69	17 769.28	21 423.45	53 357.30
1998	8 471.74	11.55	5 643.60	17 627.97	21 284.44	53 039.29
1999	8 573.86	11.69	5 683.07	17 688.82	21 401.00	53 358.44
2000	8 809.86	12.01	5 810.31	18 012.14	21 858.14	54 502.47
2001	8 946.02	12.20	5 870.61	18 116.76	22 073.88	55 019.47
2002	8 922.02	12.17	5 825.58	17 887.47	21 904.58	54 551.82
2003	8 787.65	11.98	5 709.16	17 441.90	21 466.81	53 417.50
2004	8 751.94	11.93	5 657.53	17 197.32	21 272.70	52 891.42
2005	8 773.67	11.96	5 643.22	17 067.62	21 218.89	52 715.37
2006	8 799.68	12.00	5 631.65	16 947.03	21 175.37	52 565.73
2007	8 954.55	12.21	5 702.11	17 072.84	21 440.31	53 182.03
2008	9 146.93	12.47	5 795.49	17 265.23	21 791.43	54 011.56
2009	9 350.62	12.75	5 894.92	17 473.21	22 165.31	54 896.82
2010	9 624.51	13.12	6 037.25	17 805.17	22 700.48	56 180.54
2011	9 827.82	13.40	6 133.96	17 999.48	23 064.12	57 038.79
2012	9 976.80	13.61	6 195.81	18 089.60	23 296.67	57 572.49
2013	10 158.19	13.85	6 276.92	18 234.32	23 601.64	58 284.92
2014	10 260.77	13.99	6 308.60	18 234.26	23 720.76	58 538.38
2015	10 453.78	14.26	6 395.13	18 391.48	24 046.13	59 300.79

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.12

ENERGY USE IN THE CEMENT INDUSTRY SENSITIVITY CASES

(terajoules)

	Fuel Oil		LPG		Electricity		Coal		Natural Gas		Total	
	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]
1962	6 271.87	6 283.86	7.89	7.91	3 993.03	4 000.68	11 136.96	11 158.30	16 812.30	16 844.51	38 222.06	38 295.28
1963	5 925.63	5 932.01	7.56	7.57	3 841.46	3 845.60	10 959.67	10 971.47	15 835.84	15 852.90	36 570.16	36 609.55
1964	6 003.05	6 007.32	7.76	7.77	3 954.75	3 957.55	11 519.09	11 527.27	16 026.51	16 037.88	37 511.16	37 537.79
1965	6 067.90	6 075.19	7.94	7.95	4 054.11	4 058.98	12 032.42	12 046.88	16 216.02	16 235.50	38 378.38	38 424.49
1966	6 737.29	6 364.92	8.82	8.42	4 501.34	4 304.15	13 359.80	12 991.49	18 004.92	17 061.38	42 612.17	40 730.37
1967	7 455.03	6 899.22	9.76	9.22	4 980.89	4 712.59	14 783.06	14 437.68	19 923.04	18 587.01	47 151.78	44 645.72
1968	7 690.14	7 194.46	10.06	9.69	5 137.97	4 948.93	15 249.27	15 343.86	20 551.34	19 421.46	48 638.78	46 918.40
1969	8 109.18	7 639.50	10.61	10.36	5 417.94	5 276.22	16 080.22	16 506.12	21 671.21	20 602.13	51 289.17	50 034.32
1990	8 581.02	7 488.87	11.23	10.19	5 733.19	5 177.38	17 015.86	16 294.37	22 932.16	20 114.78	54 273.46	49 085.59
1991	8 691.09	7 484.39	11.37	10.21	5 806.73	5 163.91	17 234.12	16 300.95	23 226.31	19 961.76	54 969.62	48 921.23
1992	8 689.60	7 447.56	11.37	10.16	5 805.73	5 112.81	17 231.16	16 139.63	23 222.32	19 664.89	54 960.18	48 375.06
1993	8 616.80	7 343.78	11.28	10.01	5 757.09	5 016.35	17 086.80	15 827.19	23 027.77	19 206.65	54 499.74	47 403.99
1994	8 690.17	7 390.68	11.37	10.06	5 806.11	5 023.15	17 232.29	15 832.70	23 223.84	19 155.35	54 963.77	47 411.97
1995	8 875.15	7 550.35	11.61	10.30	5 929.70	5 106.01	17 599.10	16 069.63	23 718.19	19 402.86	56 133.75	48 139.14
1996	8 940.47	7 587.59	11.70	10.35	5 973.35	5 105.54	17 728.64	16 035.83	23 892.77	19 342.55	56 546.93	48 081.86
1997	8 979.19	7 578.57	11.75	10.33	5 999.22	5 073.97	17 805.42	15 896.64	23 996.25	19 174.66	56 791.83	47 734.18
1998	8 981.59	7 346.15	11.75	10.02	6 000.81	4 893.77	17 810.16	15 285.85	24 002.64	18 456.51	56 806.96	45 992.30
1999	9 077.86	7 376.16	11.88	10.06	6 065.15	4 889.19	18 001.10	15 217.83	24 259.97	18 411.44	57 415.98	45 904.67
2000	9 310.92	7 538.93	12.18	10.28	6 220.85	4 972.10	18 463.22	15 413.66	24 882.76	18 704.82	58 889.94	46 639.78
2001	9 458.69	7 591.07	12.38	10.35	6 319.58	4 981.45	18 756.24	15 372.82	25 277.66	18 730.60	59 824.54	46 686.30
2002	9 433.97	7 485.56	12.35	10.21	6 303.06	4 887.66	18 707.22	15 007.57	25 211.60	18 377.92	59 668.19	45 768.93
2003	9 283.28	7 269.20	12.15	9.91	6 202.38	4 722.65	18 408.40	14 428.04	24 808.89	17 757.48	58 715.09	44 187.28
2004	9 255.15	7 154.87	12.11	9.76	6 183.59	4 625.13	18 352.62	14 059.12	24 733.71	17 390.82	58 537.19	43 239.71
2005	9 293.49	7 081.71	12.16	9.66	6 209.20	4 554.95	18 428.65	13 776.20	24 836.17	17 126.91	58 779.68	42 549.43
2006	9 315.94	7 000.62	12.19	9.55	6 224.21	4 480.28	18 473.18	13 482.28	24 896.19	16 846.15	58 921.71	41 818.88
2007	9 477.14	7 027.38	12.40	9.58	6 331.91	4 474.92	18 792.83	13 398.48	25 326.98	16 826.01	59 941.27	41 736.36
2008	9 672.52	7 091.35	12.66	9.67	6 462.45	4 493.07	19 180.27	13 385.24	25 849.12	16 894.26	61 177.02	41 873.59
2009	9 847.94	7 174.13	12.89	9.78	6 579.64	4 522.79	19 528.11	13 406.06	26 317.91	17 006.01	62 286.48	42 118.77
2010	10 101.26	7 346.27	13.22	10.02	6 748.90	4 608.16	20 030.44	13 590.47	26 994.89	17 327.00	63 888.71	42 881.91
2011	10 300.46	7 442.78	13.48	10.15	6 881.98	4 645.36	20 425.44	13 631.33	27 527.23	17 466.87	65 148.59	43 196.49
2012	10 449.14	7 485.11	13.67	10.21	6 981.32	4 648.42	20 720.26	13 571.75	27 924.56	17 478.36	66 088.96	43 193.84
2013	10 644.13	7 571.81	13.93	10.33	7 111.60	4 678.75	21 106.93	13 591.67	28 445.67	17 592.42	67 322.26	43 444.98
2014	10 798.42	7 547.95	14.13	10.29	7 214.68	4 640.68	21 412.87	13 413.34	28 858.00	17 449.29	68 298.10	43 061.55
2015	11 052.86	7 638.19	14.46	10.42	7 384.68	4 672.69	21 917.42	13 437.96	29 537.97	17 569.62	69 907.40	43 328.89

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

[a] Sensitivity case with unchanged energy intensities, reflecting no further conservation.

[b] Sensitivity case with unchanged export parameters, reflecting a stagnant manufacturing sector.

TABLE D.13

ENERGY USE IN ALUMINUM SMELTING
BASE CASE
(terajoules)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	14 188.39	126.39	6 950.43	481.78	783.14	22 530.13
1983	14 531.00	130.09	7 146.88	497.88	806.89	23 112.73
1984	14 837.75	133.50	7 319.75	512.48	829.72	23 633.20
1985	15 164.96	137.13	7 496.21	527.46	854.84	24 180.61
1986	15 523.93	141.08	7 681.37	543.21	882.99	24 772.58
1987	15 888.87	145.13	7 861.94	558.77	912.83	25 367.54
1988	16 275.17	149.25	8 036.91	574.08	941.59	25 977.00
1989	16 683.00	153.45	8 205.25	589.05	969.06	26 599.81
1990	17 112.62	157.72	8 365.95	603.62	995.01	27 234.92
1991	17 564.32	162.04	8 518.02	617.69	1 019.23	27 881.31
1992	18 038.47	166.42	8 660.48	631.19	1 041.51	28 538.07
1993	18 516.92	170.83	8 801.29	644.69	1 063.79	29 197.53
1994	18 998.65	175.28	8 939.96	658.16	1 086.01	29 858.05
1995	19 482.55	179.74	9 075.99	671.55	1 108.10	30 517.93
1996	19 967.50	184.22	9 208.88	684.82	1 130.00	31 175.42
1997	20 452.32	188.69	9 338.15	697.94	1 151.65	31 828.76
1998	20 935.81	193.15	9 463.32	710.87	1 172.99	32 476.14
1999	21 416.72	197.59	9 583.89	723.56	1 193.93	33 115.69
2000	21 893.76	201.99	9 699.39	735.98	1 214.42	33 745.54
2001	22 365.60	206.34	9 809.34	748.08	1 234.39	34 363.75
2002	22 832.50	210.65	9 913.98	759.88	1 253.86	34 970.86
2003	23 295.14	214.92	10 013.71	771.40	1 272.87	35 568.03
2004	23 752.78	219.14	10 108.33	782.62	1 291.39	36 154.26
2005	24 204.71	223.31	10 197.64	793.53	1 309.38	36 728.56
2006	26 650.19	227.42	10 281.48	804.09	1 326.81	37 289.99
2007	25 088.50	231.46	10 359.65	814.30	1 343.65	37 837.57
2008	25 518.91	235.43	10 432.00	824.13	1 359.86	38 370.34
2009	25 941.47	239.33	10 498.70	833.58	1 375.47	38 888.55
2010	26 360.14	243.19	10 561.45	842.80	1 390.68	39 398.26
2011	26 775.55	247.02	10 620.61	851.80	1 405.53	39 900.52
2012	27 187.70	250.83	10 676.25	860.59	1 420.03	40 395.40
2013	27 596.61	254.60	10 728.46	869.17	1 434.18	40 883.01
2014	20 002.28	258.34	10 777.30	877.53	1 447.99	41 363.45
2015	28 404.71	262.05	10 822.87	885.69	1 461.46	41 836.78

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.14

ENERGY USE IN ALUMINUM SMELTING SENSITIVITY CASES
(terajoules)

	Fuel Oil		LPG		Electricity		Coal		Natural Gas		Total	
	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]
1982	14 188.39	14 188.39	126.39	126.39	6 950.43	6 950.43	481.78	481.78	783.14	783.14	22 530.13	22 530.13
1983	14 531.00	14 531.00	130.09	130.09	7 146.88	7 146.88	497.88	497.88	806.89	806.89	23 112.73	23 112.73
1984	14 837.75	14 837.75	133.50	133.50	7 319.75	7 319.75	512.48	512.48	829.72	829.72	23 633.20	23 633.20
1985	15 164.96	15 164.96	137.13	137.13	7 496.21	7 496.21	527.46	527.46	854.84	854.84	24 180.61	24 180.61
1986	15 601.94	15 173.19	141.08	137.90	7 712.22	7 507.82	542.66	530.93	879.47	863.04	24 877.37	24 212.88
1987	16 048.96	15 203.00	145.13	138.86	7 933.18	7 522.57	558.21	534.66	904.67	873.42	25 590.15	24 272.51
1988	16 505.17	15 265.89	149.25	140.00	8 158.69	7 538.52	574.06	538.46	930.38	883.20	26 317.57	24 366.06
1989	16 969.67	15 363.89	153.45	141.32	8 388.30	7 556.47	590.23	542.48	956.57	892.44	27 058.22	24 496.60
1990	17 441.56	15 499.15	157.72	142.85	8 612.56	7 577.17	606.65	546.71	983.17	901.20	27 810.65	24 667.08
1991	17 919.86	15 673.96	162.04	144.60	8 857.99	7 601.27	623.28	551.21	1 010.12	909.54	28 573.31	24 880.58
1992	18 403.61	15 890.72	166.42	146.60	9 097.11	7 629.32	640.11	556.04	1 037.40	917.50	29 344.64	25 140.19
1993	18 891.75	16 137.31	170.83	148.88	9 338.40	7 670.24	657.09	561.84	1 064.91	927.08	30 122.99	25 445.36
1994	19 383.22	16 416.64	175.28	151.46	9 581.35	7 724.96	674.18	568.71	1 092.62	938.41	30 906.65	25 800.20
1995	19 876.92	16 724.72	179.74	154.30	9 826.39	7 791.26	691.35	576.49	1 120.45	951.26	31 693.85	26 198.00
1996	20 371.65	17 056.14	184.22	157.36	10 069.95	7 866.18	708.56	584.97	1 148.34	965.34	32 482.75	26 629.99
1997	20 866.33	17 405.34	188.69	160.56	10 314.46	7 946.96	725.77	593.96	1 176.22	980.06	33 271.46	27 086.91
1998	21 359.60	17 766.70	193.15	163.91	10 558.29	8 030.83	742.92	603.26	1 204.03	995.43	34 058.00	27 560.13
1999	21 850.25	18 134.60	197.59	167.31	10 800.83	8 115.15	759.99	612.66	1 231.68	1 010.96	34 840.33	28 040.69
2000	22 336.94	18 503.36	201.99	170.71	11 041.40	8 197.37	776.92	622.01	1 259.12	1 026.36	35 616.37	28 519.80
2001	22 818.33	18 867.24	206.34	174.06	11 279.36	8 274.99	793.66	631.07	1 286.25	1 041.31	36 383.94	28 988.68
2002	23 294.68	19 222.14	210.65	177.34	11 514.83	8 346.34	810.23	639.73	1 313.10	1 055.59	37 143.49	29 441.14
2003	23 766.66	19 567.24	214.92	180.52	11 748.14	8 411.22	826.65	647.96	1 339.71	1 069.17	37 896.10	29 876.12
2004	24 233.59	19 914.30	219.14	183.72	11 978.94	8 474.81	842.89	656.15	1 366.02	1 082.70	38 640.59	30 311.68
2005	24 694.67	20 262.74	223.31	186.94	12 206.85	8 536.86	858.92	664.29	1 392.03	1 096.13	39 375.77	30 746.97
2006	25 149.17	20 609.63	227.42	190.14	12 431.52	8 596.18	874.73	672.29	1 417.64	1 109.32	40 100.48	31 177.56
2007	25 596.35	20 952.00	231.46	193.30	12 652.57	8 651.59	890.29	680.04	1 442.85	1 122.11	40 813.51	31 599.03
2008	26 035.47	21 286.92	235.43	196.39	12 869.53	8 701.98	905.56	687.45	1 467.60	1 134.36	41 513.59	32 007.09
2009	26 466.58	21 612.21	239.33	199.39	13 082.73	8 746.61	920.56	694.47	1 491.90	1 145.93	42 201.10	32 398.61
2010	26 893.72	21 929.61	243.19	202.32	13 293.87	8 786.32	935.41	701.15	1 515.98	1 156.94	42 882.18	32 776.34
2011	27 317.54	22 237.66	247.02	205.16	13 503.37	8 820.64	950.15	707.44	1 539.87	1 167.33	43 557.96	33 138.23
2012	27 738.04	22 537.14	250.83	207.92	13 711.23	8 850.04	964.78	713.36	1 563.57	1 177.13	44 228.45	33 485.61
2013	28 155.23	22 831.23	254.60	210.64	13 917.45	8 875.87	979.29	719.08	1 587.09	1 186.53	44 893.66	33 823.34
2014	28 569.11	23 199.96	258.34	213.30	14 122.03	8 898.23	993.68	724.53	1 610.42	1 195.53	45 553.59	34 151.55
2015	28 979.69	23 408.34	262.05	215.91	14 324.99	8 917.23	1 007.96	729.74	1 633.56	1 204.13	46 208.26	34 470.35

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

[a] Sensitivity case with unchanged energy intensities, reflecting no further conservation.
[b] Sensitivity case with unchanged export parameters, reflecting a stagnant manufacturing sector.

TABLE D.15

TOTAL INDUSTRIAL ENERGY USE
BASE CASE
(petajoules)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	452.58	12.31	413.78	48.06	723.18	1649.91
1983	461.53	12.53	426.42	49.09	735.81	1685.39
1984	475.60	12.93	439.62	50.58	757.82	1736.56
1985	482.81	13.18	447.47	51.48	772.41	1767.35
1986	493.88	13.56	458.46	52.80	794.02	1812.72
1987	506.35	14.00	470.62	54.27	817.91	1863.15
1988	518.18	14.40	482.17	55.62	839.28	1909.65
1989	529.74	14.73	493.06	56.87	858.20	1952.61
1990	543.15	15.05	503.36	58.07	874.09	1993.72
1991	558.14	15.35	512.69	59.21	887.61	2033.00
1992	571.03	15.55	520.09	60.12	897.32	2064.11
1993	580.00	15.65	525.99	60.78	904.36	2086.78
1994	588.30	15.76	531.83	61.46	912.64	2109.98
1995	596.65	15.89	537.78	62.17	922.08	2134.56
1996	603.91	16.03	542.64	62.75	929.15	2154.48
1997	610.44	16.17	547.00	63.27	935.32	2172.19
1998	615.52	16.24	550.84	63.68	940.18	2186.46
1999	620.88	16.30	555.13	64.15	945.90	2202.35
2000	627.71	16.41	560.69	64.78	954.39	2223.98
2001	634.40	16.52	566.15	65.37	962.07	2244.52
2002	640.02	16.61	570.55	65.81	966.55	2259.54
2003	643.65	16.67	573.31	66.01	966.58	2266.21
2004	648.87	16.76	576.39	66.30	968.03	2276.36
2005	653.70	16.87	579.64	66.60	969.78	2286.59
2006	658.54	16.98	582.68	66.89	971.36	2296.45
2007	664.40	17.10	586.13	67.25	973.97	2308.84
2008	671.84	17.22	589.79	67.69	977.46	2324.00
2009	677.96	17.33	593.13	68.03	979.28	2335.73
2010	688.35	17.49	597.39	68.63	984.47	2356.32
2011	697.66	17.62	601.19	69.13	988.01	2373.62
2012	704.38	17.73	604.49	69.46	988.89	2384.96
2013	716.41	17.87	608.40	70.08	993.39	2406.16
2014	723.02	17.96	610.96	70.35	992.89	2415.18
2015	732.50	18.09	614.49	70.82	995.66	2431.57

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.16

TOTAL INDUSTRIAL ENERGY USE
SENSITIVITY CASES
(petajoules)

	Fuel Oil		LPG		Electricity		Coal		Natural Gas		Total	
	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]	x1[a]	x2[b]
1982	452.50	452.59	12.30	12.31	413.59	413.79	48.04	48.06	723.07	723.20	1649.50	1649.94
1983	461.46	461.54	12.53	12.54	426.18	426.43	49.08	49.09	735.81	735.83	1685.07	1685.42
1984	475.53	475.61	12.93	12.93	439.34	439.63	50.57	50.58	757.86	757.84	1736.24	1736.59
1985	482.75	482.82	13.18	13.18	447.18	447.48	51.47	51.48	772.40	772.43	1766.98	1767.39
1986	497.55	487.16	13.52	13.42	456.05	452.51	52.82	52.10	793.49	783.66	1813.43	1788.85
1987	513.27	494.31	13.91	13.75	466.42	459.31	54.30	52.99	816.31	799.04	1864.21	1819.40
1988	527.26	501.21	14.24	14.05	475.55	465.89	55.54	53.82	834.42	812.82	1907.01	1847.80
1989	541.96	509.09	14.57	14.32	486.06	472.67	56.94	54.67	855.33	826.33	1954.88	1877.08
1990	559.48	516.67	14.95	14.51	498.03	477.64	58.53	55.25	878.39	832.88	2009.38	1896.95
1991	577.36	527.45	15.29	14.72	508.29	482.57	59.91	55.93	896.04	839.56	2056.88	1920.22
1992	592.67	536.36	15.54	14.84	517.04	485.83	61.07	56.40	910.46	842.90	2096.78	1936.34
1993	603.84	541.33	15.69	14.86	524.33	487.66	61.99	56.62	922.44	843.63	2128.30	1944.10
1994	614.15	545.67	15.85	14.89	531.54	489.49	62.92	56.87	935.69	845.75	2160.16	1952.67
1995	624.42	550.16	16.04	14.95	538.97	491.55	63.90	57.18	950.52	849.28	2193.85	1963.12
1996	633.57	553.68	16.23	15.01	545.49	492.65	64.77	57.36	963.68	850.70	2223.74	1969.39
1997	641.86	556.39	16.43	15.06	551.59	493.24	65.58	57.47	976.27	851.06	2251.73	1973.22
1998	648.55	556.77	16.56	15.03	557.28	492.74	66.31	57.39	987.97	848.40	2276.67	1970.33
1999	655.40	558.23	16.67	15.00	563.43	493.26	67.09	57.44	1000.75	848.14	2303.34	1972.07
2000	663.70	561.17	16.84	15.03	570.96	495.12	68.05	57.66	1016.80	850.77	2336.35	1979.75
2001	671.84	563.94	17.02	15.06	578.49	496.86	69.00	57.85	1032.69	852.57	2369.03	1986.28
2002	678.75	565.64	17.16	15.06	584.93	497.59	69.79	57.89	1045.47	851.26	2396.10	1987.46
2003	683.56	565.33	17.28	15.04	589.62	496.66	70.32	57.68	1053.42	845.57	2414.19	1980.28
2004	690.11	566.61	17.44	15.05	594.77	496.07	70.97	57.57	1063.29	841.34	2436.58	1976.65
2005	696.29	567.42	17.62	15.08	600.11	495.58	71.63	57.46	1073.64	837.28	2459.29	1972.81
2006	702.43	568.18	17.79	15.10	605.19	494.84	72.27	57.33	1083.56	832.99	2481.25	1968.43
2007	709.69	569.89	17.97	15.13	610.71	494.41	72.99	57.27	1094.77	829.58	2506.13	1966.28
2008	718.58	573.14	18.16	15.16	616.40	494.17	73.80	57.29	1106.90	827.04	2533.84	1966.81
2009	726.02	575.03	18.34	15.19	621.56	493.58	74.48	57.20	1116.84	822.84	2557.24	1963.84
2010	737.89	581.19	18.56	15.25	627.71	493.91	75.45	57.37	1130.68	822.13	2590.29	1969.86
2011	748.71	586.21	18.76	15.30	633.35	493.74	76.32	57.45	1143.04	819.71	2620.17	1972.41
2012	756.92	588.56	18.95	15.32	638.46	493.02	77.01	57.35	1152.69	814.61	2644.03	1968.86
2013	770.62	596.25	19.16	15.37	644.28	492.93	78.02	57.53	1166.61	813.26	2678.68	1975.33
2014	778.93	596.31	19.33	15.37	648.88	491.34	78.68	57.35	1175.59	806.59	2701.41	1968.95
2015	790.24	603.31	19.54	15.40	654.60	490.74	79.59	57.38	1188.53	803.37	2732.50	1970.20

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

[a] Sensitivity case with unchanged energy intensities, reflecting no further conservation.
[b] Sensitivity case with unchanged export parameters, reflecting a stagnant manufacturing sector.

TABLE D.17

ENERGY INTENSITY PARAMETERS
THE PULP AND PAPER INDUSTRY
(megajoules per dollar)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	31.814	0.118	24.422	2.444	24.127	82.926
1983	31.082	0.118	24.940	2.391	23.910	82.441
1984	30.430	0.118	25.399	2.345	23.718	82.010
1985	29.851	0.118	25.795	2.308	23.552	81.625
1986	29.344	0.118	26.125	2.278	23.411	81.276
1987	28.904	0.118	26.386	2.255	23.294	80.957
1988	28.528	0.118	26.624	2.235	23.178	80.682
1989	28.214	0.118	26.837	2.217	23.062	80.448
1990	27.960	0.118	27.025	2.201	22.946	80.251
1991	27.765	0.118	27.187	2.188	22.832	80.089
1992	27.626	0.118	27.323	2.177	22.717	79.961
1993	27.488	0.118	27.459	2.166	22.604	79.835
1994	27.350	0.118	27.597	2.155	22.491	79.711
1995	27.213	0.118	27.735	2.145	22.378	79.589
1996	27.077	0.118	27.873	2.134	22.267	79.469
1997	26.942	0.118	28.013	2.123	22.155	79.351
1998	26.807	0.118	28.153	2.113	22.044	79.235
1999	26.673	0.118	28.293	2.102	21.934	79.121
2000	26.540	0.118	28.435	2.092	21.825	79.009
2001	26.407	0.118	28.577	2.081	21.715	78.899
2002	26.275	0.118	28.720	2.071	21.607	78.791
2003	26.144	0.118	28.864	2.060	21.499	78.685
2004	26.013	0.118	29.008	2.050	21.391	78.580
2005	25.883	0.118	29.153	2.040	21.284	78.478
2006	25.754	0.118	29.299	2.030	21.178	78.378
2007	25.625	0.118	29.445	2.019	21.072	78.280
2008	25.497	0.118	29.592	2.009	20.967	78.183
2009	25.369	0.118	29.740	1.999	20.862	78.089
2010	25.242	0.118	29.889	1.989	20.758	77.996
2011	25.116	0.118	30.039	1.979	20.654	77.906
2012	24.991	0.118	30.189	1.969	20.550	77.817
2013	24.866	0.118	30.340	1.960	20.448	77.731
2014	24.741	0.118	30.491	1.950	20.345	77.646
2015	24.618	0.118	30.644	1.940	20.244	77.563

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.18

ENERGY INTENSITY PARAMETERS THE IRON AND STEEL INDUSTRY

(megajoules per dollar)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	9.218	0.142	14.420	0.055	29.255	53.090
1983	9.016	0.142	14.362	0.055	28.991	52.566
1984	8.844	0.142	14.319	0.054	28.759	52.119
1985	8.703	0.142	14.290	0.053	28.558	51.747
1986	8.590	0.142	14.276	0.053	28.387	51.448
1987	8.504	0.142	14.276	0.052	28.245	51.219
1988	8.427	0.142	14.276	0.052	28.075	50.973
1989	8.360	0.142	14.276	0.051	27.879	50.708
1990	8.301	0.142	14.276	0.051	27.656	50.426
1991	8.251	0.142	14.276	0.050	27.407	50.126
1992	8.210	0.142	14.276	0.049	27.133	49.810
1993	8.173	0.142	14.269	0.048	26.848	49.481
1994	8.141	0.142	14.255	0.048	26.553	49.138
1995	8.112	0.142	14.233	0.047	26.247	48.782
1996	8.088	0.142	14.205	0.046	25.932	48.413
1997	8.068	0.142	14.169	0.046	25.608	48.033
1998	8.051	0.142	14.127	0.045	25.275	47.641
1999	8.039	0.142	14.077	0.045	24.934	47.238
2000	8.031	0.142	14.021	0.044	24.585	46.824
2001	8.027	0.142	13.958	0.044	24.228	46.400
2002	8.027	0.142	13.888	0.043	23.865	45.966
2003	8.027	0.142	13.819	0.043	23.507	45.538
2004	8.027	0.142	13.750	0.043	23.154	45.116
2005	8.027	0.142	13.681	0.042	22.807	44.700
2006	8.027	0.142	13.612	0.042	22.465	44.289
2007	8.027	0.142	13.544	0.041	22.128	43.883
2008	8.027	0.142	13.477	0.041	21.796	43.483
2009	8.027	0.142	13.409	0.040	21.469	43.088
2010	8.027	0.142	13.342	0.040	21.147	42.699
2011	8.027	0.142	13.275	0.040	20.830	42.315
2012	8.027	0.142	13.209	0.039	20.517	41.935
2013	8.027	0.142	13.143	0.039	20.210	41.561
2014	8.027	0.142	13.077	0.038	19.907	41.192
2015	8.027	0.142	13.012	0.038	19.608	40.828

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.19

ENERGY INTENSITY PARAMETERS THE PETROLEUM REFINING INDUSTRY (megajoules per dollar)

Year	Fuel Oil	LPG	Electricity	Natural Gas	Total
1982	0.024	0.001	4.238	14.849	19.112
1983	0.024	0.001	4.196	14.700	18.920
1984	0.023	0.001	4.154	14.553	18.731
1985	0.023	0.001	4.112	14.408	18.543
1986	0.022	0.001	4.071	14.264	18.358
1987	0.022	0.001	4.030	14.121	18.174
1988	0.021	0.001	3.998	13.994	18.014
1989	0.021	0.001	3.974	13.882	17.878
1990	0.021	0.001	3.958	13.785	17.764
1991	0.020	0.001	3.950	13.702	17.674
1992	0.020	0.001	3.950	13.633	17.605
1993	0.020	0.001	3.950	13.565	17.536
1994	0.020	0.001	3.950	13.497	17.468
1995	0.020	0.001	3.950	13.430	17.401
1996	0.020	0.001	3.950	13.363	17.333
1997	0.019	0.001	3.950	13.296	17.267
1998	0.019	0.001	3.950	13.230	17.200
1999	0.019	0.001	3.950	13.163	17.134
2000	0.019	0.001	3.950	13.098	17.068
2001	0.019	0.001	3.950	13.032	17.002
2002	0.019	0.001	3.950	12.967	16.937
2003	0.019	0.001	3.950	12.902	16.872
2004	0.019	0.001	3.950	12.838	16.807
2005	0.019	0.001	3.950	12.773	16.743
2006	0.018	0.001	3.950	12.710	16.679
2007	0.018	0.001	3.950	12.646	16.615
2008	0.018	0.001	3.950	12.583	16.552
2009	0.018	0.001	3.950	12.520	16.489
2010	0.018	0.001	3.950	12.457	16.426
2011	0.018	0.001	3.950	12.395	16.364
2012	0.018	0.001	3.950	12.333	16.302
2013	0.018	0.001	3.950	12.271	16.240
2014	0.018	0.001	3.950	12.210	16.179
2015	0.018	0.001	3.950	12.149	16.118

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.20

ENERGY INTENSITY PARAMETERS
THE INDUSTRIAL CHEMICALS INDUSTRY
(megajoules per dollar)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	13.798	0.155	24.452	0.634	83.868	122.906
1983	13.729	0.155	24.550	0.637	83.868	122.938
1984	13.660	0.155	24.624	0.640	83.868	122.947
1985	13.592	0.155	24.673	0.644	83.868	122.931
1986	13.524	0.155	24.697	0.647	83.868	122.891
1987	13.456	0.155	24.697	0.650	83.868	122.826
1988	13.402	0.155	24.673	0.653	83.784	122.666
1989	13.362	0.155	24.623	0.655	83.616	122.411
1990	13.336	0.155	24.550	0.656	83.365	122.061
1991	13.322	0.155	24.451	0.657	83.032	121.617
1992	13.322	0.155	24.329	0.657	82.617	121.079
1993	13.322	0.155	24.207	0.656	82.162	120.503
1994	13.322	0.155	24.086	0.656	81.669	119.888
1995	13.322	0.155	23.966	0.655	81.139	119.236
1996	13.322	0.155	23.846	0.653	80.571	118.547
1997	13.322	0.155	23.727	0.652	79.966	117.822
1998	13.322	0.155	23.608	0.650	79.327	117.062
1999	13.322	0.155	23.490	0.647	78.652	116.267
2000	13.322	0.155	23.373	0.645	77.944	115.439
2001	13.322	0.155	23.256	0.642	77.204	114.579
2002	13.322	0.155	23.140	0.639	76.432	113.687
2003	13.322	0.155	23.024	0.636	75.668	112.804
2004	13.322	0.155	22.909	0.632	74.911	111.929
2005	13.322	0.155	22.794	0.629	74.162	111.062
2006	13.322	0.155	22.680	0.626	73.420	110.204
2007	13.322	0.155	22.567	0.623	72.686	109.353
2008	13.322	0.155	22.454	0.620	71.959	108.510
2009	13.322	0.155	22.342	0.617	71.240	107.675
2010	13.322	0.155	22.230	0.614	70.527	106.848
2011	13.322	0.155	22.119	0.611	69.822	106.028
2012	13.322	0.155	22.008	0.607	69.124	105.216
2013	13.322	0.155	21.898	0.604	68.432	104.412
2014	13.322	0.155	21.789	0.601	67.748	103.615
2015	13.322	0.155	21.680	0.598	67.071	102.826

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.21

ENERGY INTENSITY PARAMETERS
THE MIXED FERTILIZER INDUSTRY
(megajoules per dollar)

Year	Fuel Oil	LPG	Electricity	Natural Gas	Total
1982	0.138	0.082	1.104	0.453	1.776
1983	0.136	0.082	1.088	0.446	1.753
1984	0.135	0.082	1.074	0.440	1.732
1985	0.133	0.082	1.061	0.435	1.712
1986	0.132	0.082	1.050	0.430	1.694
1987	0.131	0.082	1.039	0.426	1.678
1988	0.129	0.082	1.030	0.422	1.664
1989	0.128	0.082	1.022	0.419	1.651
1990	0.127	0.082	1.014	0.416	1.639
1991	0.126	0.082	1.008	0.413	1.630
1992	0.124	0.082	1.003	0.411	1.621
1993	0.123	0.082	0.998	0.409	1.613
1994	0.122	0.082	0.993	0.407	1.605
1995	0.121	0.082	0.988	0.405	1.596
1996	0.119	0.082	0.983	0.403	1.588
1997	0.118	0.082	0.978	0.401	1.580
1998	0.117	0.082	0.974	0.399	1.572
1999	0.116	0.082	0.969	0.397	1.564
2000	0.115	0.082	0.964	0.395	1.556
2001	0.114	0.082	0.959	0.393	1.548
2002	0.112	0.082	0.954	0.391	1.540
2003	0.111	0.082	0.949	0.389	1.532
2004	0.110	0.082	0.945	0.387	1.524
2005	0.109	0.082	0.940	0.385	1.517
2006	0.108	0.082	0.935	0.383	1.509
2007	0.107	0.082	0.931	0.382	1.501
2008	0.106	0.082	0.926	0.380	1.494
2009	0.105	0.082	0.921	0.378	1.486
2010	0.104	0.082	0.917	0.376	1.479
2011	0.103	0.082	0.912	0.374	1.471
2012	0.102	0.082	0.908	0.372	1.464
2013	0.101	0.082	0.903	0.370	1.456
2014	0.100	0.082	0.898	0.368	1.449
2015	0.099	0.082	0.894	0.367	1.441

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.22

ENERGY INTENSITY PARAMETERS
THE CEMENT INDUSTRY
(megajoules per dollar)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	26.330	0.033	16.763	46.755	70.580	160.462
1983	25.962	0.033	16.830	48.017	69.381	160.223
1984	25.624	0.033	16.881	49.169	68.409	160.117
1985	25.317	0.033	16.915	50.202	67.657	160.123
1986	25.038	0.033	16.932	51.106	67.116	160.224
1987	24.788	0.033	16.932	51.872	66.780	160.404
1988	24.589	0.033	16.915	52.443	66.379	160.359
1989	24.442	0.033	16.881	52.810	65.915	160.080
1990	24.344	0.033	16.830	52.968	65.387	159.563
1991	24.295	0.033	16.763	52.915	64.799	158.805
1992	24.295	0.033	16.679	52.651	64.151	157.809
1993	24.295	0.033	16.596	52.361	63.541	156.827
1994	24.295	0.033	16.513	52.047	62.969	155.858
1995	24.295	0.033	16.430	51.709	62.434	154.902
1996	24.295	0.033	16.348	51.347	61.935	153.958
1997	24.295	0.033	16.266	50.962	61.470	153.027
1998	24.295	0.033	16.185	50.554	61.040	152.107
1999	24.295	0.033	16.104	50.124	60.643	151.200
2000	24.295	0.033	16.023	49.673	60.279	150.304
2001	24.295	0.033	15.943	49.201	59.948	149.421
2002	24.295	0.033	15.864	48.709	59.648	148.549
2003	24.295	0.033	15.784	48.222	59.350	147.685
2004	24.295	0.033	15.705	47.740	59.053	146.827
2005	24.295	0.033	15.627	47.262	58.758	145.976
2006	24.295	0.033	15.549	46.790	58.464	145.131
2007	24.295	0.033	15.471	46.322	58.172	144.293
2008	24.295	0.033	15.394	45.859	57.881	143.462
2009	24.295	0.033	15.317	45.400	57.591	142.637
2010	24.295	0.033	15.240	44.946	57.303	141.818
2011	24.295	0.033	15.164	44.497	57.017	141.006
2012	24.295	0.033	15.088	44.052	56.732	140.200
2013	24.295	0.033	15.013	43.611	56.448	139.401
2014	24.295	0.033	14.937	43.175	56.166	138.607
2015	24.295	0.033	14.863	42.743	55.885	137.820

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

TABLE D.23

ENERGY INTENSITY PARAMETERS THE ALUMINUM SMELTING INDUSTRY (megajoules per dollar)

Year	Fuel Oil	LPG	Electricity	Coal	Natural Gas	Total
1982	22.580	0.201	11.061	0.767	1.246	35.855
1983	22.467	0.201	11.050	0.770	1.248	35.735
1984	22.354	0.201	11.028	0.772	1.250	35.606
1985	22.243	0.201	10.995	0.774	1.254	35.466
1986	22.131	0.201	10.951	0.774	1.259	35.317
1987	22.021	0.201	10.896	0.774	1.265	35.157
1988	21.933	0.201	10.831	0.774	1.269	35.007
1989	21.867	0.201	10.755	0.772	1.270	34.865
1990	21.823	0.201	10.669	0.770	1.269	34.732
1991	21.801	0.201	10.573	0.767	1.265	34.607
1992	21.801	0.201	10.467	0.763	1.259	34.491
1993	21.801	0.201	10.362	0.759	1.252	34.376
1994	21.801	0.201	10.259	0.755	1.246	34.263
1995	21.801	0.201	10.156	0.751	1.240	34.150
1996	21.801	0.201	10.055	0.748	1.234	34.039
1997	21.801	0.201	9.954	0.744	1.228	33.928
1998	21.801	0.201	9.855	0.740	1.221	33.819
1999	21.801	0.201	9.756	0.737	1.215	33.710
2000	21.801	0.201	9.658	0.733	1.209	33.603
2001	21.801	0.201	9.562	0.729	1.203	33.497
2002	21.801	0.201	9.466	0.726	1.197	33.391
2003	21.801	0.201	9.372	0.722	1.191	33.287
2004	21.801	0.201	9.278	0.718	1.185	33.184
2005	21.801	0.201	9.185	0.715	1.179	33.082
2006	21.801	0.201	9.093	0.711	1.173	32.980
2007	21.801	0.201	9.002	0.708	1.168	32.880
2008	21.801	0.201	8.912	0.704	1.162	32.781
2009	21.801	0.201	8.823	0.701	1.156	32.682
2010	21.801	0.201	8.735	0.697	1.150	32.585
2011	21.801	0.201	8.648	0.694	1.144	32.488
2012	21.801	0.201	8.561	0.690	1.139	32.392
2013	21.801	0.201	8.475	0.687	1.133	32.298
2014	21.801	0.201	8.391	0.683	1.127	32.204
2015	21.801	0.201	8.307	0.680	1.122	32.111

SOURCE: The Socio-Economic Resource Framework, University of Waterloo, March 1989.

GLOSSARY

AGGLOMERATION: Conversion of small pieces of low grade iron into larger pieces by applying heat.

ALKYLATION: A refinery process that reacts light C_3 and C_4 olefins with isobutane (both of which are in the gas phase at ambient conditions) to produce high-octane gasoline blending components. This process uses either sulphuric acid or hydrofluoric acid as a catalyst.

ALLOY STEELS: Iron to which other elements such as C, Cr, Ni, W, Mn and Mo have been added.

ANNEALING: To heat and subsequently to cool a substance in a controlled way for such purposes as inducing ductility in metals, producing a desired microstructure, or obtaining desired mechanical, physical or other properties.

AROMATICS: Cyclic hydrocarbons and their derivatives; characterized by the presence of at least once **benzene** ring. The principal aromatics are benzene, toluene and xylene.

ATMOSPHERIC BOTTOMS: The residues from a refinery's first distillation, at atmospheric pressure, of crude oil into its natural boiling point components. These residues normally have initial boiling points of approximately 650°F. The bottoms product can be used in **residual fuel oil** blending or as a feedstock.

BEATING: A mechanical shearing and abrading process by which pulp fibres are split or frayed to improve the strength and formability of the subsequent sheet.

BENEFICIATION: Improving the chemical or physical properties of an ore so that the metal can be recovered at a profit. Also known as mineral dressing.

BENZENE (C_6H_6): A colourless, liquid hydrocarbon made from coal tar and by catalytic reforming of naphthenes. It is used (1) in the manufacture of phenol, styrene, nylon, detergents, aniline, naphthalic anhydride and other compounds; (2) as a solvent; and (3) as a component of high-octane gasoline.

BITUMEN: A general name for various solid and semi-solid hydrocarbons; a naturally occurring, dark-coloured mixture (e.g., tar), comparatively hard and non-volatile and composed principally of hydrocarbons.

BITUMINOUS: Coal containing much organic, or at least carbonaceous matter, mostly in the form of tarry hydrocarbons. Also known as soft coal.

BLACK LIQUOR: See **liquor**.

BLOWDOWN: Removal of liquids or solids from a process or storage vessel or line by the use of pressure.

BOILER: A closed vessel in which a liquid is heated and/or vaporized. Often classified as to steam or hot water, low pressure or high pressure, capable of burning one fuel or a number of fuels.

BOILER EFFICIENCY: The ratio of the heat output to the heat input expressed in percent.

BOTTOMING CYCLE: A means of increasing the **thermal efficiency** of a steam electric generating system by converting some waste heat from the condenser into electricity rather than discharging all of it into the environment.

BOX ANNEALING: Slowly heating and cooling a ferrous metal in a sealed container under conditions that minimize oxidation.

BREEZE: See **coke breeze**.

BUNKER FUEL: The grade of **residual fuel oil** used to power ships.

CALENDAR: To press between rollers or plates to smooth, to glaze or to thin into sheets.

CAPACITY: The maximum power output or load for which a machine, apparatus, station or system is rated.

CARBON BLACK: A form of carbon produced commercially by thermal or oxidative decomposition of hydrocarbons and used principally in rubber goods, pigments and printer's ink.

CARBON DIOXIDE (CO_2): A colourless, odorless, tasteless gas about 1.5 times as dense as air.

CARBONIZATION: The destructive distillation of coal accompanied by the formation of char (coke), liquid (tar), and gaseous products.

CARBURIZE: To surface-harden steel by converting the outer layer of low-carbon steel to high-carbon steel by heating the steel above the transformation range in contact with carbonaceous material.

CASE HARDENING: A generic term covering several processes applicable to steel that change the chemical composition of the surface layer by absorption of carbon, nitrogen, or a mixture of the two and, by diffusion, create a concentration gradient. The processes commonly used are carburizing and quench hardening; cyaniding; nitriding; and carbonitriding.

CAST: To pour molten metal or plastic into a mold where it cools and solidifies.

CAST IRON: Impure form of iron containing considerable (2-5 percent) carbon, plus silicon, manganese, phosphorous, sulphur and other alloys. Cast iron's advantages are low cost, excellent castability, and good machinability; disadvantages are relatively low strength and low ductility.

CATALYST (CATALYZER): A material that brings about a chemical reation without being permanently changed itself in the process.

CATALYTIC CRACKING: A refinery process in which heavy petroleum fractions are converted into light components by contact with a catalyst at high temperatures (nearly 1,000°F). This process primarily produces high-octane gasoline blending components. It is a cheaper process than **hydrocracking**, but produces a less attractive yield of products.

CATALYTIC REFORMING: Rearrangement of hydrocarbon molecules in a gasoline boiling range feedstock to form hydrocarbons having a higher antiknock quality.

CAUSTICIZE: In the pulp and paper industry; to treat green liquor with burned lime or other alkaline material during the preparation of fresh digester liquor.

COAL GASIFICATION: A controlled process of reacting coal, steam, and oxygen under pressure and elevated temperature. The crude gas is purified and has a low heating value. Subsequent catalytic upgrading can be employed to produce high BTU pipeline grade gas.

COGENERATION: The simultaneous production of power and useful heat in one technological process.

COKE: The solid residue remaining from the dry distillation of coking coal, pitch, petroleum or other carbonaceous material.

COKE BREEZE: The undersized coke screenings that can pass through openings of approximately 16 millimetres (5/8 inch).

COKING: A refinery process that converts heavy residual petroleum fractions (such as bottoms product from **vacuum distillation**) into lighter products and petroleum coke. The petroleum coke yield typically represents about 25 percent of the feed.

COKING COAL: The most important of the **bituminous** coals, it burns with a long yellow flame and creates an intense heat when properly attended.

COLD FORMING: Any forging operation that uses compressed force to shape metal and is performed cold; low temperature permits close dimensional accuracy.

CONDENSATE: In petroleum refining, hydrocarbons in a gaseous state under reservoir conditions at high pressures, which become liquid at the surface or under reduced pressures.

CONSISTENCY: The percentage by weight of solids in a water suspension of wood chips or fibre used for pulp, paper or board manufacture.

CONTINUOUS FURNACE: A furnace used for heat treatment of materials, with or without direct firing; pieces are loaded through one door, progress continuously through the furnace, and are discharged from another door.

CONTINUOUS VACUUM FURNACE: A furnace that refines molten steel by reducing the hydrogen content. The steel is passed from the ladle through a vacuum chamber operated by pumps and into the ingot molds. Also known as vacuum degassing and vacuum casting.

CONVECTION: Heat transfer by the movement of fluid.

CRACKING: A process used to reduce the molecular weight of hydrocarbons by breaking molecular bonds through thermal, catalytic, or hydrocracking methods. See **catalytic cracking**.

CUPOLA: A vertical, cylindrical furnace for melting gray iron (pig or cast iron in which the carbon not contained in the pearlite is present in the form of graphitic carbon) for foundry use; the metal, coke and flux are put into the top of the furnace onto a bed of coke through which air is blown.

DECARBURIZATION: Loss of carbon from the surface layer of a carbon-containing alloy due to reactions with one or more chemical substances in a medium that contacts the surface.

DESULPHURIZATION: The process by which sulphur and sulphur compounds are removed from gases or liquid hydrocarbon mixtures.

DIAPHRAGM CELL: An electrolytic cell used to produce sodium hydroxide and chlorine from sodium chloride brine; in this cell a porous diaphragm separates the anode and cathode compartments.

DIE CASTING: A metal casting process in which molten metal is forced under pressure into a permanent mold.

DIESEL FUEL: Fuel used for internal combustion diesel engines; usually that fraction of crude oil that distills after kerosene; similar to gas oil.

DIGESTER: A vessel in which wood chips, etc., are cooked with chemical solutions to produce pulp.

DIRECT REDUCTION PLANTS: Plants employing any of several methods for extracting iron ore below the melting point of iron; they produce a solid reduced iron that may be converted to steel with little further refining.

DIRECT RESISTANCE HEATING: A process in which electric current is passed through special resistors in the form of coils, rods, grids, or baths of molten salt with high electrical resistance, and are heated by their resistance to the flow of the current.

DISTILLATE FUEL OIL: The lighter fuel oils distilled during the refining process, includes such products as ASTM grades No. 1 and 2 heating oils, diesel fuels, and No. 4 fuel oil. The major uses of distillate fuel oils include heating, fuel for on- and off-highway diesel engines, and railroad diesel fuel.

DISTILLATION: The process of producing a gas or vapour from a liquid by heating the liquid in a vessel and collecting and condensing the vapours into liquids. See also **fractional distillation**.

EFFLUENT: A liquid, solid, or gaseous product, frequently waste, discharged from a process; generally used to describe discharges into water.

ELECTRIC ARC FURNACE: A furnace that heats materials by the energy from a discharge of electricity through a gas.

ELECTROLYSIS: A method for effecting chemical reaction by passing an electrical current through the solution of an electrolyte (i.e., a chemical compound that will conduct an electric current) or through molten salt.

ENDOTHERMIC: Pertaining to a reaction that absorbs heat.

ENDOTHERMIC ATMOSPHERE: A gas mixture produced by the partial combustion of a hydrocarbon gas with air in an endothermic reaction. Also known as endogas.

ENTHALPY: The heat content per unit mass, expressed in BTU per pound.

ETHYLENE (C_2H_4): A colourless, flammable gas used as an agricultural chemical, in medicine, and for the manufacture of organic chemicals and ployethylene. Also called ethane or olefant gas.

EXOTHERMIC: Pertaining to a reaction, such as fuel combustion, that liberates heat.

EXOTHERMIC ATMOSPHERE: A gas mixture produced by the partial combustion of a hydrocarbon gas with air in an exothermic reaction. Also known as exogas.

EXTRUSION: Forming (plastics, metals, etc.) by forcing through a die.

FEEDSTOCK: Fossil fuels used for their chemical properties, rather than for their value as a fuel, e.g., oil used to produce plastics and synthetic fabrics. A raw material that can be converted to one or more end products (methanol or synthetic natural gas, for example).

FINE PAPER: Grades of paper containing less than 8 percent filler (non-fiber solids) by weight.

FINISHING: The treating of the surface of metal products to give them better resistance to corrosion, wear, or fatigue and a better appearance.

FIRED HEATERS: Furnaces in which heat input is derived from fuel combustion (flames); can be direct-fired (flame in contact) or indirect-fired (flame separated from the process fluid by a metallic wall).

FLAME HARDENING: A process for hardening the surfaces of ferrous metals in which an intense flame is used to heat the surface layers above the upper transformation temperature, whereupon the workpiece is immediately quenched.

FLASH DRYER: Dryers for wood particles or wood fibers where the material is dried in a high-velocity, high-temperature air stream in a manner that exposes the maximum surface area of each particle to the atmosphere, resulting in a short drying time.

FLASH FURNACE: In the production of molten metal, a vertical furnace in which concentrates are reacted with hot gases; the molten product is collected in a horizontal, refractory-lined accumulator at the base of the furnace. Also called a flash **smelter**.

FLUE: Passage for combustion products within furnace or boiler.

FLUE GAS: Gas from the combustion of fuel, the heating value of which has been substantially spent and discarded to the flue or stack.

FLUIDIZED BED: The process in which a fluid, usually a gas, flows upward through a bed of suitably-sized solid particles at a velocity high enough to buoy the particles, to overcome the influence of gravity and to impart great turbulence.

FORGING: Using compressive force, usually in combination with heat, to shape metal.

FOURDRINIER MACHINE: A papermaking machine in which a thin sheetlike stream of fiber suspension is directed onto a porous, horizontal moving belt, forming a mat. After water is removed from the mat by gravity and suction, the sheet passes over rollers and into press and dryer sections.

FRACTION: The portion of a volatile liquid that boils within a certain temperature range.

FRACTIONAL DISTILLATION: The separation of a mixture of several volatile components of different boiling points; the mixture is distilled at the lowest boiling point, and the distillate is collected as one fraction until the temperature of the vapour rises, showing that the next higher boiling component of the mixture is beginning to distill; this component is then collected as a separate fraction.

FRACTIONATION: Separation of a mixture in successive stages, each stage removing from the mixture some proportion of one of the substances; for example, using differential solubility in water-solvent mixtures.

FREEZE-DRY: To preserve by rapid freezing and drying in vacuum.

FUEL GAS: Synthetic gas used for heating and cooling and having less energy content than pipeline quality gas.

FUEL OIL: Any liquid or liquefiable petroleum product burned for the generation of heat in a furnace or firebox, or for the generation of power from an engine.

GALVANIZE: To deposit zinc on the surface of metal by hot dipping, sherardizing (tumbling in the powdered zinc) or electrolytic deposition.

GAS FRACTIONATION: Recovers light hydrocarbons and sulphur contaminants from by-product gases before they are used as fuel.

GRAIN: The particles or discrete crystals that compromise a metal.

GREEN LIQUOR: See **liquor**.

GROUNDWOOD: A mechanical process in which wood bolts are reduced to pulp by pressing on a revolving grindstone, or in which chips are mechanically fiberized to a pulp.

HEAT CONTENT: The amount of heat produced by the complete combustion of a unit quantity of fuel. Also called heating value.

HEAT EXCHANGER: A device that transfers heat from one fluid to another, or to the environment.

HEAT TREATMENT: Heating and cooling a metal or alloy to obtain desired properties or conditions.

HEAVY CRUDE: Crude oil having a high proportion of viscous, high-molecular-weight hydrocarbons, and often having a high sulphur content.

HOGGED WOOD OR BARK: Wood waste and/or bark reduced to a relatively uniform particle size and used for fuel.

HOT ROLLING: Rolling of metal products after heating

HOT WORKING: Plastic deformation (permanent change in shape or size without fracture) of a metal at such a rate and temperature that strain hardening (increasing hardness and tensile strength by cold plastic deformation) cannot occur.

HYDROCRACKING: A refinery process that reacts heavy liquid petroleum fractions in the presence of a catalyst, in a hydrogen-rich environment; sulphur is removed, and high yields of lighter boiling products are obtained. More severe than hydrotreating, the process entails high operating pressures (200 psig), high hydrogen consumption, and high capital costs, but produces good yields.

HYDROGENATION: Catalytic reaction of hydrogen with other compounds usually unsaturated; for example, unsaturated oils are hydrogenated to form solid fats.

HYDROLYSIS: A chemical reaction of water and another compound in which a bond of the other reactant is broken and a proton and a hydroxyl ion are added; the reaction may break complex organic molecules into simple ones, such as the hydrolysis of cellulose to glucose.

HYDROPOWER: The generation of electricity by an elevated water supply as it moves to a lower level, employing a rotating shaft or water wheel attached to a generator. Also called hydroelectric power.

HYDROTREATING: A refinery process in which a hydrocarbon stream is treated by chemical reaction by contact with a catalyst in a hydrogen atmosphere. This process reduces sulphur content, removes nitrogen, and improves other product qualities. Also called hydro desulphurization.

INDUCTION HARDENING: A surface-hardening process in which only the surface layer of a suitable ferrous workpiece is heated by electromagnetic induction to above the upper critical temperature and immediately **quenched**.

INDUCTION HEATING: The passing of a high- or medium-frequency alternating current through a coil surrounding (but not in contact with) the material to be heated.

INFRA-RED RADIATION: The radiation in that portion of the electromagnetic spectrum between visible light and radio waves, originating from either incandescent or non-incandescent hot bodies, or from flames. The energy is utilized as a means of direct heat transfer from the source to the object, or objects, to be heated without materially heating the intervening air.

INFRA-RED RADIANT HEATER: A self-contained, vented or unvented heater, used to convert combustion energy to radiant energy, a substantial portion of which is in the infra-red spectrum, for the purpose of direct heat transfer.

INGOT IRON: Relatively pure iron containing less than 0.25 percent impurities.

INORGANIC CHEMICALS: Elements and compounds, except carbon compounds having hydrogen-carbon or carbo-carbon linkages.

ISOMERIZATION: Rearranges parafin molecules to improve their octane value for gasoline.

KRAFT PULPING: A wood pulping process in which sodium sulphate is used in the caustic soda pulp **digester liquor**.

LIGHT CRUDE: Crude oil having a high proportion of low-viscosity, low-molecular-weight hydrocarbons.

LIGHT ENDS: The lower-boiling components of a mixture of hydrocarbons, such as those evaporated or distilled off early in comparison to the bulk of the mixture.

LIGHT OIL: Any of the products distilled or processed from crude oil up to, but not including, the first lubricating oil.

LIGNIN: An amorphous polymer found with cellulose in the woody cells of plants, but not hydrolyzable in acid.

LIGNITE: Coal of a relatively recent origin; intermediate between peat and bituminous. Characterized by low quality, high water content, and low heating valve.

LIME KILN: Furnace-type apparatus, usually a long, tilted cylinder that is slowly rotated; used to heat calcium carbonate above 900°C to produce lime.

LIQUEFACTION: Any change in the phase of a substance to the liquid state.

LIQUEFIED GASES: Derived by refining or otherwise processing natural gas, crude oil or unfinished oils, the following gases may be liquefied: ethane, propane, **butane**, **ethylene**, propylene and butylene.

LIQUEFIED NATURAL GAS: Natural gas converted to a liquid under cryogenic conditions by cooling to -260°F. The liquid is both tasteless and odorless, almost pure methane, and occupies 1/600 of its gaseous volume at normal temperatures.

LIQUID PETROLEUM GAS (LPG): Liquified propane and butane mixture distributed under pressure from tanks.

LIQUOR: In paper and pulp manufacture, black liquor is the spent reagent solution from the pulp digestion step in the **kraft** process. Green liquor is the solution of dissolved smelt from the kraft recovery furnace. Red liquor is the spent reagent solution from the pulp digestion step in the **sulphite process.** White liquor is the fresh draft cooking liquor formed by **causticizing** and clarifying green liquor.

LUBRICANT: Oil, grease, graphite, and in general anything of the sort used to overcome friction and permit a freer action of parts.

MARKET PULP: Pulp produced for sale.

METALLURGICAL COAL: Coal with strong or moderately strong coking properties that contains no more than 8 percent ash and 1.25 percent sulphur, as mined or after conventional cleaning.

METHANE (CH_4): The lightest in the paraffinic series of hydrocarbons; colourless, odorless, and flammable, it forms the major portion of marsh gas and natural gas.

MIDDLE DISTILLATE: The distillates, including light fuel oils and diesel fuels, obtained between kerosene and lubricating oil in the refining process.

MILL SCALE: The heavy oxide layer formed during hot fabrication or heat treatment of metals.

NAPHTHA: Petroleum fraction with volatility between that of gasoline and kerosene, used as a gasoline ingredient, solvent for paints, rubber and cleaning solvent. Also an aromatic solvent from coal tar, either solvent naphtha or heavy naphtha.

NAPPING: Passing a fabric over revolving cylinders covered with points or burrs to raise the surface fibres.

NATURAL GAS: Naturally occurring mixture of low-molecular-weight paraffinic hydrocarbons, generated below the surface of the earth and found in either a gaseous state or in solution with crude oil. Important components of natural gas are propane, butane, pentane, **methane**, ethane and hexane.

NITRIDING: Process of case hardening in which a ferrous metal is heated in an atmosphere of ammonia or other nitrogen-bearing material. Extreme hardness is produced at the metal surface by absorption of nitrogen and the resultant formation of hard nitrides.

NITROCARBURIZING: Any of several processes in which both nitrogen and carbon are absorbed into the surface layers of a ferrous metal at temperatures below the lower critical temperature and, by diffusion, create a concentration gradient. Nitrocarburizing is done mainly to provide an antiscuffing surface layer and to improve fatigue resistance.

OCTANE NUMBER: A rating used to measure the antiknock properties of liquid motor fuel.

OLEFIN (C_nH_{2n}): A family of unsaturated, chemically active hydrocarbons with at least one carbon-carbon double bond; includes **ethylene** and propylene.

ORGANIC CHEMICALS: Those chemicals having carbon-carbon and/or carbon hydrogen bonds.

OVEN DRY: Condition describing a paper or board product containing zero moisture. Also called bone dry.

PARALLEL GENERATION: Customer-owned and operated generation equipment which is linked with the electric grid.

PAYBACK PERIOD: The length of time before the earnings of a procedure have paid for the amount of money invested in it.

PELLETIZING: Forming aggregates of about 13 millimetres (1/2 inch) diameter from finely divided ore or coal.

PETROCHEMICALS: Chemicals made from feedstocks derived from petroleum or **natural gas**; examples are **ethylene**, butadiene, most **plastics** and resins, and petrochemical sulphur. Also called petroleum chemicals.

PICKLE: To treat metal by immersion in an acidic or alkaline solution to remove oxide or **mill scale** from the surface.

PREHEATING: Heating a metal slowly and uniformly to one or more temperatures below the critical temperature in order to minimize thermal shock, relieve internal stresses, and minimize exposure time.

PRIMARY METALS: Metals that are obtained directly from their natural sources and from their own production processes as contrasted with secondary metals obtained from recycled scrap.

PRIME MOVER: Mechanical equipment, such as an engine or turbine, which converts the energy of a fuel or fluid into mechanical power, usually rotational.

PROCESS FURNACE: A furnace used to heat process stream materials (liquids, gases or solids) in a chemical plant operation: types are direct fired, indirect fired and pebble heaters (gas heating devices in which heat is transferred to the gas via a countercurrent movement of preheated pebbles).

PROCESS HEAT: Heat used during the actual manufacturing of a product.

PROCESS STEAM: Steam, often superheated, used as a primary source of heat in a production operation.

PULP: A manufactured fibrous cellulosic material used in the production of paper, board and cellulose derivatives such as synthetic yarns and films. Pulp is made chiefly from wood, but also from other vegetable materials.

PYROLYSIS: A chemical change brought about by the application of heat.

QUENCHING: Cooling rapidly, as by plunging in water, to prevent the formation of precipitate at too high a temperature and to promote hardening.

RADIATION: The transmission of energy by means of electromagnetic waves of generally long wave length. Radiant energy of any wave length may, when absorbed, become thermal energy and result in an increase in the temperature of the absorbing body.

RAPSON PROCESS: A **kraft** process characterized by a complete absence of aqueous effluents.

RECOVERY: In the pulp and paper industry, the processing of spent **digester liquor** to regenerate pulping chemicals and to exploit the heating value or other valuable properties of the material.

RECOVERY HEAT: Heat exchanged between process streams; the heat that is passed through a processing unit and is recirculated (recycled) back through the process.

RECUPERATOR: A furnace apparatus in which heat is conducted from the combustion products to incoming cooler air or fuel through a system of thin-walled ducts.

REDUCING ATMOSPHERE: Furnace atmosphere with excess carbon.

REFINER MECHANICAL PULPING (RMP): In the pulp and paper industry, a process in which chips are fed to high-speed disk mills where they are torn into component fibers at atmospheric pressure by a combination of mechanical rubbing and hydraulic shear.

REFINERY GAS: A mixture of gases, including carbon monoxide, hydrogen, **methane**, and ethane, produced as by-products in the conversion of crude petroleum.

REFRACTORY: Any non-metallic ceramic of high melting point, such as silica and magnesite, which may be used as lining for furnaces.

REFRACTORY ORE: An ore capable of withstanding extremely high temperature and having relatively low thermal conductivity.

REGENERATIVE FURNACE: A furnace that uses potential waste substances by reclaiming and recirculating them to reheat the same operation or to participate in another.

REGENERATOR: Same as a recuperator, except that gaseous products of combustion heat brick checkerwork in a chamber to the exhaust side of the furnace while the incoming air and fuel are being heated by brick checkerwork in a second chamber, connected at the entrance side. At intervals, the gas flow is reversed so that incoming air and fuel contact hot checkerwork while that in the second chamber is being reheated by exhaust gases.

RESIDUAL FUEL OIL: The heavier oils that remain after **distillate fuel oils** and lighter hydrocarbons are boiled off during refinery operations. Included are Nos. 5 and 6 oil, heavy diesel oil, and sludge and pitch used as refiner oils.

RESISTANCE FURNACE: An electric furnace in which the heat is developed by the passage of current through a suitable internal resistor, which may be the charge itself, a resistor imbedded in the charge, or a resistor surrounding the charge. Also called electric resistance furnace.

RETROFIT: To modify existing equipment to be more energy efficient; or to adjust a piece of equipment to perform a different function, such as using a different fuel, without changing its basic structure or process.

REVERBERATORY FURNACE: A furnace in which heat radiates (reverberates) from a low roof onto the material being treated.

ROTARY FURNACE: A heat-treating furnace of circular construction which rotates the workpiece around the axis of the furnace during heat treatment. Also called a rotary hearth furnace.

SCRUBBER, ROTARY: A piece of equipment for removing impurities from gas by passing the gas over rotating surfaces or brushes that are partially immersed in liquid.

SCRUBBER, TOWER: A vertical vessel filled with plates or suitable packing over which scrubbing liquid flows while the gas to be purified flows upward through the liquid, separating entrained liquids or solids from the gas.

SELF-GENERATION: The same as customer-owned generation except that in some jurisdictions (e.g., in Ontario) self-generation relates only to generators which are not interconnected with the grid.

SINTER: To heat metal powders until a coherent bonded mass is formed, with or without previous compacting and without melting.

SLAG: A nonmetallic product resulting from the interaction of flux and impurities in the smelting and refining of metals.

SLAG PROCESS: The interaction of flux and impurities in the **smelting** and refining of metals resulting in a nonmetallic phase containing the impurities.

SMELT: In the primary metals industry, to melt or fuse ores, separating the metallic constituents. In the pulp and paper industry, the mixture of molten inorganic material, chiefly sulphides and carbonates, obtained when concentrated spent **digester liquor** is burned in a **recovery** furnace.

SOAKING: Holding a metal at a specified temperature for a period of time.

SOLVENT EXTRACTION: A method of extracting one or more substances from a mixture by treating a solution of the mixture with a solvent that will dissolve the required substances and leave the others; used in purifying certain fuels.

SPHEROIDIZING: Heating and cooling to produce a spheroidal or globular form of carbide in steel.

SPONGE IRON: Iron in porous or powder form made without fusion by heating iron ore in a reducing gas or with charcoal.

STOCK: In the pulp and paper industry, a liquid suspension of pulp, with or without added chemicals.

STRAIGHT-RUN DISTILLATION: Continuous nonreactive distillation of petroleum to separate it into products (called straight-run or virgin fractions) in the order of their boiling points.

STRESS RELIEVING: Low temperature heating to reduce residual stress, followed by slow cooling to minimize the development of new residual stresses.

SULPHITE PROCESS: In the pulp and paper industry, a chemical process whereby wood chips are reduced under steam pressure to pulp with an acid chemical (calcium, magnesium, sodium, or ammonium bisulphate plus sulphurous acid).

TEMPERING: **Heat treatment** of hardened steels to temperatures below the transformation temperature range, usually to improve toughness.

THERMAL CRACKING: Converts heavy fraction of crude to mixture of gases, light products and residual oil.

THERMAL EFFICIENCY: The percentage of total energy content of a power plant's fuel that is converted into electricity, the remainder being lost to the environment as heat. The efficiency of any energy conversion is the ratio of useful work, or energy output, to work, or energy input.

THERMOMECHANICAL PULPING (TMP): In the pulp and paper industry, a system of refining wood chips in a pressurized environment with steam and chemicals or in a gas phase, followed by nominal washing, screening, rejects refining, etc.; eliminates or minimizes the traditional digestion step and subsequent washing and liquor recovery.

TOPPING: In the refinery operation of crude oil, the initial step of heating the oil at near atmospheric pressure.

TUYERE: An inlet hole for air blast into a **cupola** furnace.

VACUUM DISTILLATION: Liquid distillation under reduced (less than atmospheric) pressure; used to lower boiling temperatures and lessen the risk of thermal degradation during distillation. Also called reduced-pressure distillation.

VALUE ADDED: The market price of a good less the cost of materials that were purchased from others (material, fuels and electricity) and were used to fabricate that good. A measure of the amount of production at any stage; the difference between the value of the output of a stage of production and the value of all intermediate products purchased as inputs at that stage.

VISBREAKING: Mild thermal **cracking** of the heavy fraction of crude to produce light fuel oil.

WET END: The mat-forming portion of a paper or board machine, upstream of the press section.

WHITE LIQUOR: See **Liquor**.

WHITE WATER: The solution, containing papermaking chemicals and fiber fines, that drains from the fiber mat on a paper machine as pulp is converted into paper or board.

WIRE: In papermaking, the moving screen or fabric belt on which the matter is formed in a **Fourdrinier machine**.

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